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Number interference in sentence processing

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Declaration

I declare that this thesis was composed by myself, that the work herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted either in the same or different form, to this or any other University for a degree.

Katja Suckow **Signature:** Katja Suckow Date: 12/07/2013

Declaration

I certify that Katja Suckow has spent the equivalent of at least nine terms on research work under my supervision and that she has fulfilled the conditions of Ordinance No 39 so that she is qualified to submit this thesis for the degree of Doctor of Philosophy.

Dr. Roger van Gompel **Signature:** Dr. Roger van Gompel Date: 12/07/2013

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Abstract

This thesis presents six eye-tracking experiments that investigate the time-course of similarity based interference caused by number congruency of two noun phrases. In addition, effects of number congruency were dissociated from effects of number attraction.

Experiments 1 and 2 contrasted effects of number congruency in object-relative with subject relative clauses. Models of interference in sentence processing (Lewis & Vasishth, 2005; Van Dyke & Lewis, 2003; Van Dyke 2007) claim that object relatives clauses (1) are harder to understand than subject-relatives (2). According to these models, an interference effect arises at the verb (*counted*) for object relatives because there are two noun phrases (*banker*, *accountant*) in memory that have to be retrieved at the verb in contrast to only one for subject relatives (*banker*). In a cue-based retrieval account, the two noun phrases in object relatives should cause even more interference when they share the same retrieval cues. Thus, object relatives should be more difficult when the preceding noun phrases have the same number (either both singular like in (1a, 2a) or both plural) than when they have a different number (one singular and the other plural like in (1b)).

Because both the relative clause effect and the number congruency effect are due to interference of the noun phrases when they are integrated with the verb (*counted*), both effects should occur at the same time.

1. (a) The banker that | the accountant helps | counted | the money | several times.

   (b) The bankers that | the accountant helps | counted | the money | several times.

2. (a) The banker that | helps the accountant | counted | the money | several times.

   (b) The bankers that | help the accountant | counted | the money | several times.

While Experiment 1 showed that object relatives were harder than subject relative clauses (in regression path and total reading times for the regions *help the accountant* and *counted*), number congruency did

not affect difficulty. This suggests that number congruency does not have a strong effect on the processing of subject or object-relative clauses. However, the effect of number interference might have been spread out over the long region after the relative clause (*counted the money several times*) and occurred together with other integrative processes.

Therefore, in Experiment 2 the region following the relative clause was shortened (without *several times*). Like in Experiment 1, object relatives took longer to read than subject relatives in regression path and in total reading times for *help the accountant*, for *counted* and for *the money*. Interestingly, there was an interaction between relative clause type and number congruency in first-pass time for the final wrap-up region (*the money*): Object relatives with congruent noun phrases were more difficult than incongruent noun phrases, whereas there was no difference with subject relatives.

The observed delay of the number congruency effect in comparison to the relative clause effect is not consistent with memory interference models. They predicted the number congruency effect to occur at the relative clause region, simultaneously with the slow-down for the object relative clause conditions. Due to the small distance between the sentence subject (*banker*) and the embedded verb (*helps*), the activation of the subject of the main clause might not have decayed enough to cause a strong number interference effect from a number congruent subject in the relative clause. Therefore, when the target has not decayed enough at memory retrieval, number interference may be weak and occurs later than the relative clause effect.

Experiments 3 and 4 investigated effects of number attraction and number interference when the target subject had more time to decay. In addition to its role during memory interference, number is also important for agreement processes in a sentence: a verb's number marking needs to agree with the number marking of its subject. Production studies (Bock & Miller, 1991; Bock & Cutting, 1992) have investigated number agreement errors (speakers often produce sentences in which the number of the verb agrees with the number of the wrong noun: *The key to the cabinets are on the table*) and Wagers, Lau, and Phillips (2009) have shown that these number attraction errors can affect the comprehension of ungrammatical sentences.

If number attraction affects the comprehension of grammatical sentences it predicts that when the sentence subject is singular (*secretary* in 3 + 4), the integration of *was on* should be more difficult when the verb is preceded by a plural noun phrase (either *customers* or *directors*) than when it is preceded by a singular noun phrase (either *customer* or *director*). Accounts of number interference, on the other hand, predict that when the subject has the same number as the intervening noun phrases (*customer* or *director*) reading times at the following verb region *was on* in (3 and 4) should increase. These predictions were tested in Experiments 3 and 4. (Experiment 4 used verbs (*argued with*) that can take a prepositional phrase as a complement, while Experiment 3 sometimes used verbs (*greeted*) that could take a sentence complement and a direct object as a complement. This ambiguity was avoided in Experiment 4.)

3 + 4. (a) The secretary | who greeted / argued_with | the customer of the director | was on | the train | to the meeting.

(b) The secretary | who greeted / argued_with | the customers of the director | was on | the train | to the meeting.

(c) The secretary | who greeted / argued_with | the customer of the directors | was on | the train | to the meeting.

(d) The secretary | who greeted / argued_with | the customers of the directors | was on | the train | to the meeting.

Experiments 3 and 4 showed an early number interference effect from NP3 (*director*). There were longer reading times at the verb region (*was on*) in first fixation duration and first-pass time in Experiment 3 and at the spillover region (*the train*) in first fixation duration in Experiment 4 when NP3 was singular (*director*) than when NP3 was plural (*directors*). In addition to that, there was a number interference effect from NP2 (*customer*) in Experiment 4. Total reading times were longer at *the train* when NP2 was singular than plural.

Thus, Experiments 3 and 4 showed that number interference from NP3 occurred early in first fixation duration (also in first-pass time in Experiment 3). However, there was also a later number interference effect from NP2 in total reading times in Experiment 4. No effect of number attraction was observed in Experiments 3 and 4. This might be because the number attractor was embedded in a relative clause and thus syntactically stronger separated from the verb. This separation might be the reason the number information did not attract to the verb.

Experiments 3 and 4 showed that effects of number interference occur early. On the other hand, the findings of Experiments 1 and 2 indicate that number interference is weak and occurs late. According to Van Dyke and Lewis (2003) and Lewis and Vasishth (2005), different types of retrieval cue overlap (e.g., verb subcategorisation, semantics, number) should all cause interference simultaneously during processing. Van Dyke (2007) compared effects of the retrieval cue overlap for verb categorisation (syntactic interference) with effects of cue overlap for animacy of the noun phrases (semantic interference). The findings of Van Dyke (2007) suggested that syntactic interference may occur before interference due to other cues, like animacy.

Using eye-tracking, Experiment 5 investigated whether interference due to number overlap would also occur later than syntactic interference. Sentences in (5) contrasted conditions where the interfering embedded noun (*journalist*) is either in object position in (5a, 5b) or in subject position in (5c, 5d). In object position, the syntactic retrieval cue of *journalist* mismatches with the target subject *photographer* and therefore conditions (5a, 5b) are syntactically less complex. In subject position, the embedded *journalist* in (5c, 5d) shares retrieval cues with the target subject *photographer* and conditions (5c) and (5d) are syntactically more complex. In order to test number interference effects, the embedded noun phrase was either plural (*journalists* in 5b, 5d) or singular (*journalist* in 5a, 5c). There should be more number interference from the embedded singular noun (*journalist*) since it is number congruent with the target subject (*photographer*). There should be even more interference from the singular noun in the syntactically complex condition since both the *journalist* in (5c) and the target *photographer* share the syntactic cue of being a subject.

5. (a) The presenter acknowledged that the photographer | who was chatting with the convincing journalist | has been | awarded | the prize.
   (b) The presenter acknowledged that the photographer | who was chatting with the convincing journalists | has been | awarded | the prize.
   (c) The presenter acknowledged that the photographer | who professed that the journalist talked convincingly | has been | awarded | the prize.
   (d) The presenter acknowledged that the photographer | who professed that the journalists talked convincingly | has been | awarded | the prize.

Similar to Van Dyke (2007), Experiment 5 found effects from syntactic cue overlap and effects due to other cues (number interference) at different points in time. However, unlike Van Dyke (2007), Experiment 5 found that interference due to the number cue overlap occurred early in first fixation duration and in first-pass time at the spillover region (*awarded*). Interference due to verb subcategorisation was observed in the later measures regression-path and total reading time at the spillover region (*awarded*). These findings indicate that number interference has a very rapid effect on sentence processing and occurs earlier than the syntactic interference effect.

There were no effects of number attraction in Experiments 3 and 4. However, Wagers et al. (2009) found that number attraction can affect the processing of ungrammatical sentences. A possible explanation might be that number attraction is not part of initial structure building, but affects processes of recovery like recovery from ungrammatical structures. Experiment 6 tested number attraction processes during syntactic ambiguity resolution. Sentences with a local ambiguity (without the comma in 6a, 6b) were compared with sentences without ambiguity (with comma in 6c, 6d). The verb *has to* not only resolves the ambiguity it also needs to agree with the subject of the preceding noun phrase (*cousin*). The number attraction account predicts that there should be longer reading times at the verb (*has to*) when it is preceded by a local plural number attractor (*farmers* in 6b, 6d) than when it is preceded by a local singular number attractor (*farmer* in 6a, 6c). Number interference, on the other hand, predicts that the reading times at the verb phrase *has to* should be longer when the preceding noun is singular (*farmer* in 6a, 6c) because the subject (*cousin*) of the verb *has to* is also singular.

6. (a) After Virginia answered the cousin of the farmer | has to | think it | all over again.
   (b) After Virginia answered the cousin of the farmers | has to | think it | all over again.
   (c) After Virginia answered, the cousin of the farmer | has to | think it | all over again.
   (d) After Virginia answered, the cousin of the farmers | has to | think it | all over again.

Experiment 6 showed a strong effect of ambiguity: ambiguous sentences were harder to process than unambiguous sentences. More importantly, there was also an interaction that showed ambiguous sentences with a local plural number attractor (*farmers* in 6b) had longer reading times than ambiguous sentences with a local singular noun (*farmer* in 6a) at the verb region (*has to*) in regression-path time. There was no attraction effect in the unambiguous sentences. Thus, number attraction seem to affect late processes of recovery like reanalysis.

Overall, number interference occurs. It occurs early if the subject activation is low and it occurs late if the subject activation is high. There was no evidence for attraction except during reanalysis.

1 Introduction: Working memory effects in sentence processing

Sometimes understanding a sentence can pose a surprising challenge. According to accounts of working memory constraints, difficulty in comprehension occurs when the working memory architecture fails to perform the necessary processes for the interpretation of a sentence.

Similarity based interference is known to affect sentence processing (Bever, 1974; Gordon, Hendrick, & Johnson, 2001; Van Dyke & Lewis, 2003; Gordon, Hendrick, Johnson, & Lee, 2006). These interference effects are expected when temporarily stored items during sentence processing are similar to each other. As a result the integration of a verb with its subject becomes difficult when the parser cannot easily identify the target subject among the list of similar potential candidates in memory. Van Dyke and Lewis (2003) introduced an account of retrieval cue parsing that quantified the similarity between items in terms of their retrieval cue information. The more a target subject in memory shares retrieval cues with other temporarily stored items, the harder it is for the parser to identify the target among a list of similar potential candidates. One such retrieval cue indicates the number information of the nouns in memory (whether the dependents are in singular or in plural). Thus, according to the retrieval cue parsing account, the integration of a verb should be more difficult when items in memory have the same number as the target subject (*The father*$_{sing}$ *that the aunt*$_{sing}$ *sees*$_{sing}$ *left the building.* - The singular noun *aunt* is interfering here.)

This thesis investigates whether these effects of number interference can be observed during sentence processing and especially: What are the circumstances and conditions for a number interference effect? A further research question concerns the time course of number interference effects in relation to interference effects caused by the overlap of other retrieval cues, e.g. syntactic cues.

Nevertheless, number information is also used to mark the agreement between a verb and its subject in a sentence. Number agreement errors have been observed and investigated in language production. Sometimes, speakers produce sentences where the verb erroneously agrees with the more recent noun phrase than with its subject: **The key to the cabinets are on the table.* If these number agreement violations (also known as number attraction) can also affect comprehension, then the integration of a verb after a number mismatching noun (*They key to the cabinets is ...*) should be harder than the integration after a number matching noun (*The key to the cabinet is...*). The number interference account, on the other hand, predicts that the integration of the verb after a number matching noun (number cue overlap) should be harder than the verb integration after a number mismatching noun, since the identification of the subject is easier when the retrieval cues can uniquely identify the target subject among the set of temporarily stored items. Thus, number attraction makes different predictions about verb integration difficulty than the number interference account. Another aim of this thesis is to investigate whether sentence processing is affected by number interference or number attraction.

The introduction of this thesis gives an overview about factors that affect sentence processing. One robust finding in sentence processing is that readers have more difficulty understanding embedded object relative clauses (*The man <u>that the women saw</u> left.*) than embedded subject relative clauses (*The man <u>that saw the women</u> left.*) Factors that have been argued to affect difficulty with these structures are: individual differences in working memory capacity (Just & Carpenter, 1992; King & Just, 1991), readers' experience with certain sentence structures (Ericsson & Kintsch, 1995; MacDonald & Christiansen, 2002), the distance (locality) between the verb (*saw*) and its dependent (*The man*) for object relatives (Gibson, 1998, 2000) and also the predictability of the upcoming sentence structure (object relatives harder to predict than subject relatives) (Hale, 2006; Levy, 2007). Further explanations for the relative clause effect include the animacy (Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005) and the topichood (Mak, Vonk, & Schriefers, 2002, 2006) of the noun phrases that have to be temporarily stored before they are integrated with the verb.

Similarity based interference is another account of sentence processing difficulty effects and stems from memory research. When similar items have to be temporarily stored in memory, they interfere with each other (Bever, 1974; Gordon et al., 2001; Van Dyke & Lewis, 2003; Gordon et al., 2006). This interference affects retrieval processes when one of the items needs to be accessed during e.g. verb integration. Van Dyke and Lewis (2003) described different informational cues that determine the similarity between items. Those include information about gender, case, animacy and number information of the item. While Van Dyke and Lewis suggested various types of cues, they don't make a distinction between different retrieval cue overlap effects. Similarity effects due to syntactic cue overlap between items might occur at a different time than effects due to number retrieval cue match. One main question that will be dealt with in this thesis is: What are the circumstances under which number interference occurs and do they occur together with interference effects caused by the overlap of other retrieval cues?

Working memory effects in sentence processing

This chapter will give an overview of theories and experiments that describe how sentence processing performance is related to limited working memory resources. Compare a notoriously difficult object-relative structure like (1a) with its subject-relative counterpart like (1b):

1. (a) **object-relative**
   The banker that the accountant helps counted the money.

   (b) **subject-relative**
   The banker that helps the accountant counted the money.

The object relative sentence (1a) is more difficult than the subject-relative sentence (1b). Readers take longer or even need to reread parts of the sentence in order to establish that *the banker counted the money* and *the accountant helps the banker* in (1a). In contrast, it is easier to structure the second sentence: *the banker counted the money* and *the banker helps the accountant* in (1b). Processing sentences becomes difficult when there are not enough working memory resources to interpret the structure. Working memory resources play a role in the processes that are necessary for a successful interpretation.

In the following chapter, I'll present literature and experimental findings in support of the idea that working memory indeed affects sentence processing.

1.1 Individual differences in language processing

Some of the first evidence that processing difficulty is affected by working memory demands comes from Daneman and Carpenter (1980). Daneman and Carpenter introduced a measure of individual working memory that they argue is more closely related to sentence processing than measures used previously. Traditional tests like *digit span tests* do not entail a reading task to differentiate between good and bad readers, which motivated Daneman and Carpenter to develop *the reading span test*. The *reading span test* is designed to test the readers' capacity for sentence processing.

To determine a reader's reading span, the participant has to read a set of sentences and is asked to memorise the final word of each of these sentences. After the presentation of the sentences, the reader had to recall these words. The number of sentences increases by one after each successful and complete recall of these words. For example the first set contains two sentences and after reading them, the reader has to recall the final words of these two sentences. The next set will contain three sentences. The test ends when the participant fails to recall the final words. The final test score is the maximal number of words that the participant was able to remember.

Daneman and Carpenter (1980) argue that by including a sentence reading task, they add a processing task to the pure memory task of the final words. Thus, the reading span score should be a better reflection of a reader's sentence comprehension performance than a score that only reflects the storage component.

To test this, readers were given three different tasks: a reading span task and a word span task and after reading a paragraph they had to answer two different kinds of comprehension questions in Experiment 1. One kind of comprehension question asked for general information about the sentence content while the second asked about the reference of the pronoun. The pronoun was always presented in the last sentence of the paragraph, the distance to its referent varied in number of sentences that separated them. Consider Example (2) below for the distance two. Distance two described that the introduction of the referent *leopard* is separated from its referring pronoun *he* by two sentences. (Daneman & Carpenter, 1980)

2. ... The proceedings were delayed because the leopard had not shown up yet. There was much speculation as to the reasons for the midnight alarm. Finally he arrived and the meeting could commence.
   (Daneman & Carpenter, 1980, p. 455)

Comprehension questions in Daneman and Carpenter (1980) tested the reader's ability for pronoun resolution over a varying number of sentences. Daneman and Carpenter (1980) predicted a correlation between the readers' comprehension performance and their reading span score.

The results showed that the span test scores were related to the readers' performance in the comprehension tasks. Low span readers showed poorer performance in comprehension than high span readers. The word span test on the other hand did not show a significant correlation between scores and the performance in any of the comprehension questions. The findings of this experiment suggest that reading span scores can be an indicator of reading comprehension. Daneman and Carpenter (1980) speculated that the reading span test should also make similar predictions for listening comprehension since working memory capacity should hold for written as well as spoken material.

In a second experiment, Daneman and Carpenter (1980) tested the same materials, but designed a span test for silent and oral reading (reading out loud) as well as listening. The results supported the findings of the first experiment. There was a high correlation between memory span and reading comprehension. The designed listening span was equally good as the reading span at predicting reading comprehension. Interestingly, the analysis of the errors showed that high span readers seemed to have some partial understanding of the sentence content while the types of errors for low span readers seem to indicate a more basic misunderstanding.

Daneman and Carpenter (1980) showed that individual working memory capacity affects language comprehension. However, the language performance they tested was investigated using general comprehension questions and pronoun resolution. After they established that working memory affects comprehension, it remained an open question whether it also affects sentence processing.

1.1.1 Individual differences in sentence processing

King and Just (1991) investigated whether the reading span test introduced by Daneman and Carpenter (1980) could affect sentences processing. As described before, Daneman and Carpenter (1980) showed that there is a correlation between the reading span test and general comprehension and pronoun resolution tasks. King and Just tested whether there is also a correlation between reading span scores and the ability to understand complex sentences. For example, object-relative clauses (structures like 3a) are known to be notoriously difficult to understand in contrast to subject-relative clauses (structures like 3b).

3. (a) **object-relative**
   The reporter | that the senator attacked | admitted the error.

   (b) **subject-relative**
   The reporter | that attacked the senator | admitted the error.
   (King & Just, 1991, p. 581)

King and Just (1991) suggested one crucial difference between object and subject-relative conditions that may explain why object relatives like (3a) are so difficult in comparison with subject relatives like (3b). While the main clauses in (3a) and (3b) are interrupted by the relative clause, *the reporter* has two different grammatical roles in (3a) in contrast to only one in (3b). In (3a) *the reporter* is the subject of the main clause and the object in the relative clause. In (3b) it is the subject for both main and relative clause. King and Just argued that because it is computationally costly to assign two roles with one single item, object relatives are harder than subject-relatives. Their hypothesis is that if individual differences in working memory affect language processing (as Daneman and Carpenter (1980, 1983) have shown for pronoun resolution), readers with a low span should have more difficulty with object-relative sentences than readers with a high-span score.

In order to test that, King and Just (1991) used the reading span method to assess the working memory capacity of the participants of their study. Assuming that the working memory span affects comprehension, King and Just predicted that, overall, object-relatives should be harder to understand, but this difficulty should be especially pronounced for readers that scored low in the memory span test.

Experiment 1 was a self-paced reading experiment that contrasted sentences containing either object- (4a) or subject-relative (4b) clauses. Participants were assigned to the *high*, *medium* or *low* span group. Sets of one, two or three sentences were presented to the participants and they were asked to remember the last word of each sentence. The final sentences in each set was the manipulated critical subject versus object relative sentence. A yes/no question probing for the comprehended information of the last of the three sentences was presented at the end of each set.

4. (a) **object-relative**
   The | reporter that the senator | attacked | admitted | the error | publicly after the hearing.

   (b) **subject-relative**
   The | reporter that attacked the | senator | admitted | the error / publicly after the hearing.
   (King & Just, 1991, p. 584)

Results of the recall rate supported the predictions and could reflect the scores of the reading span test. Overall, low span readers had a lower comprehension score than high span readers and this difference was especially pronounced in the object-relative conditions. Whereas in the subject-relative conditions, the difference between low and high span readers was not significant. Reading times showed that low span readers took longer than high span readers. This reading time difference is especially marked at the two verbs *attacked* and *admitted* in the object-relative conditions. These findings suggest that while a syntactically complex structure is difficult to process, a reader's low working memory capacity makes the processing of these structures even more difficult. (King & Just, 1991)

King and Just (1991) speculated that since low spans did not have enough capacity to interpret the syntactic cues they might have made use of *pragmatic associations* in Experiment 1. Consider the sentence in Example (5a) below where the two potential subjects are *the fireman* and *the robber* and the verb is *rescued*. Low spans might use their pragmatic knowledge and, because *the fireman* is more likely to rescue somebody than *the robber* is, assign *the fireman* as the subject of the verb *rescued*. A pragmatic resolution - if available - might be easier than a syntactic resolution. This might be an attractive strategy since low spans may not have sufficient resources for a syntactic resolution.

In order to resolve this, King and Just (1991) conducted Experiment 2 which tested object-relative sentences only, using self-paced reading. The two verbs in these structures were manipulated to either both be pragmatically biased (*rescued*, *stole* in 5a), only the verb in the relative clause was biased (*rescued* in 5b), the verb for the main clause was biased (*stole* in 5c) or none of the two verbs were biased (*detested*, *watched* in 5d). Participants' reading span was measured in Experiment 2 and after the presentation of each sentence a question probed for their comprehension accuracy. King and Just predicted that since low span readers should use the pragmatic cues to a greater extent, and so object relatives should be easier when facilitating cues are provided at the point of difficulty (see the italicised verbs in 5a, b and c).

5. (a) **both**
   The | robber that the fireman | *rescued* | *stole* | the jewelry.

   (b) **relative**
   The | robber that the fireman | *rescued* | watched | the program.

   (c) **main**
   The | robber that the fireman | detested | *stole* | the jewelry.

   (d) **neither**
   The | robber that the fireman | detested | watched | the program.
   (King & Just, 1991, p. 592)

Overall, comprehension accuracy rates in Experiment 2 were lower for the conditions without any pragmatic cues (5d) in contrast to those with pragmatic cues (5a, b and c). The comprehension scores for high span readers were higher than those for low capacity readers, and this was the case even when a pragmatic cue was present. For low spans, comprehension ratings were higher when the comprehension question asked for information in the relative clause with pragmatic information (5a and b) than when there was no pragmatic information (5c and d). King and Just (1991) concluded that high span readers can use pragmatic cues in the relative clause as well as in the main clause, while low span readers can make use of the pragmatic information only locally for the relative clause.

The reading time data of Experiment 2 also showed that low span readers were slower at the verb of the main clause than high span readers.

The observations in reading time and comprehension accuracy of both of these self-paced reading experiments suggest that syntactic processing is indeed affected by the working memory capacity of readers.

1.1.2 A capacity theory of comprehension

Just and Carpenter (1992) claimed that comprehension is constrained by working memory capacity. Their model of working memory aimed to integrate the functions of *storage* and *integration*. When heads and dependents in a sentence are separated by intervening material, dependents have to be intermittently *stored* in order to be *integrated* with their heads. Consider the object-relative sentence from Example (3a): *The reporter that the senator attacked admitted the error. Reporter* and *senator* are dependents of the head (*attacked*) and *reporter* is separated from the head (*attacked*) by the intervening *senator*. In order for the *reporter* to be integrated with its head *attacked* has to be stored until *senator* is integrated and the verb *attacked* is encountered.

Just and Carpenter (1992) described this storage process in terms of the activation of information. If the activation of an item in memory falls below a certain threshold, it is no longer in working memory and thus not available for further processing: it is forgotten. The ability to keep this information active in memory varies among readers.

To show the effect of constrained capacity on comprehension Just and Carpenter (1992) presented the results of an eye tracking study which repeated the study of Ferreira and Clifton (1986). Ferreira and Clifton showed that when presented with a sentence that contained a local ambiguity, readers initially adopted the structurally simplest, rather than the most plausible interpretation.

In examples (6a) and (6c), *the evidence* is inanimate and thus an implausible agent of *examined*, whereas *the defendant* in (6b) and (6d) is animate and a plausible agent. In the ambiguous conditions (6c and d), the roles of *the defendant* and *the evidence* for the verb *examined* are ambiguous until the phrase *by the lawyer* needs to be integrated into the sentence. Reading times on the *by*-phrase indicate whether readers erroneously assumed *the defendant* and *the evidence* to be the agent of *examined* in the ambiguous conditions: since *by the lawyer* does not fit into a sentence structure in which *the defendant* and *the evidence* are agents of *examined*, this interpretation will have to be changed during the integration of *by the lawyer*. Ferreira and Clifton (1986) tested whether this reanalysis should be easier for the conditions with an implausible agent (6c) since *the evidence* is less likely to be initially interpreted as the agent of *examined*.

6. (a) **implausible / unambiguous**
   The evidence that was examined by the lawyer shocked the jury.

   (b) **plausible / unambiguous**
   The defendant who was examined by the lawyer shocked the jury.

   (c) **implausible / ambiguous**
   The evidence examined by the lawyer shocked the jury.

   (d) **plausible / ambiguous**
   The defendant examined by the lawyer shocked the jury.
   (Just & Carpenter, 1992, p. 126-127)

Ferreira and Clifton (1986) reported that ambiguous conditions took longer on the *by*-phrase than the unambiguous. This difference was unaffected by the plausibility of the subject. Thus, Ferreira and Clifton (1986) found that despite the plausibility cue provided by the nouns (*evidence*, *defendant*), readers showed signs that they initially assumed *the evidence* to be the agent of the verb.

Ferreira and Clifton (1986) argued that these findings show that non-syntactic information does not have an immediate effect on syntactic processing. On the other hand, Trueswell, Tanenhaus, and Garnsey (1994) presented results from an eye-tracking study which showed plausibility effects for sentence structures like Example 6. There was an interaction effect: reduced relative clauses with animate subject noun phrases had longer reading times than reduced relative clauses with inanimate subject noun phrases. The difference between animate and inanimate subject nouns was less pronounced in unreduced relative clauses. Since the animacy of a subject can affect the comprehension difficulty of a reduced relative clause, Trueswell et al. showed that syntactic processing can actually be affected by semantic constraints.

Just and Carpenter (1992) described an eye-tracking experiment, which tested the same materials as Experiment 1 in Ferreira and Clifton (1986). The most important difference to the Ferreira and Clifton (1986) study was that participants were divided in groups of low and high-span readers. The findings differed between these two memory span groups. Low span readers were not affected by the plausibility manipulation, but high span readers experienced more difficulty when the noun was plausible (*defendant*) than when it was an implausible agent (*evidence*). Just and Carpenter (1992) concluded that these findings supported the capacity account of language processing: the high memory capacity of the high span readers enabled them to consider the animacy cues during processing, whereas the low span readers did not have enough capacity to make use of this information.

To further support their claim about capacity based sentence processing, Just and Carpenter (1992) tested the findings of MacDonald, Just, and Carpenter (1992). Readers were presented with sentences that contained a local ambiguity, see Example (7). Both sentences (7a) and (7b) contained a local ambiguity. The phrase *warned about the dangers* could either entail the main verb of the sentence or it can be interpreted as a reduced relative clause. This ambiguity will be resolved when the next word (*before* in (7a) and *conducted* for (7b)) is encountered. Both conditions differ in the interpretation of the final sentence interpretation. The item *before* in (7a) can only be integrated into a structure where *warned* is the main verb of the sentence. The verb *conducted* in (7b), on the other hand, disambiguated the interpretation of the previous phrase: it is a reduced relative clause (<u>*that*</u> *warned about the dangers*). MacDonald et al. (1992) argued that the main clause interpretation is the reader's preferred interpretation until disambiguation either by *before* in (7a) or by *conducted* in (7b). Thus, the reanalysis initiated at *conducted* in (7b) should be harder than the disambiguation at *before* in (7a).

7. (a) **main clause / local ambiguity**
   The experienced soldiers warned about the dangers <u>before</u> the midnight raid.

   (b) **relative clause / local ambiguity**
   The experienced soldiers warned about the dangers <u>conducted</u> the midnight raid.
   (Just & Carpenter, 1992, p. 131)

Interestingly, the findings suggest that the high span readers seem to keep both interpretations for the ambiguous structures active. The reading times on *before* in (7a) were longer than the reading times on *conducted* in the disambiguating condition (7b). A possible interpretation of these findings is that readers keep both interpretations of the subject-role (*the soldier* being active or passive) active in the *before* condition. Low span readers, on the other hand, did not show this effect of ambiguity. Therefore, Just and Carpenter (1992) claimed that low span readers do not have enough resources to keep both interpretations active and accessible in memory. Thus, this study shows support for the notion of parallel activation as well as capacity constrained processing.

1.1.3 Critique on the capacity theory of sentence comprehension

The argumentation and the experiments described by Just and Carpenter (1992) received criticism from Waters and Caplan (1996). First, Waters and Caplan argued that the analysis of the Just and Carpenter experiments was not done appropriately. In their original study, Ferreira and Clifton (1986) correctly compared reduced and unreduced relative clauses with animate first nouns (8a and b) separately from reduced and unreduced conditions with inanimate nouns (9a and b).

8. (a) **implausible - unreduced**
   The evidence that was examined by the lawyer shocked the jury.

   (b) **implausible - reduced**
   The evidence examined by the lawyer shocked the jury.

9. (a) **plausible - unreduced**
   The defendant that was examined by the lawyer shocked the jury.

   (b) **plausible - reduced**
   The defendant examined by the lawyer shocked the jury.
   (Ferreira & Clifton, 1986, p. 366)

For the comparison of the reduced relative clause with the unreduced full relative clause, Ferreira and Clifton reported that readers' fixations were longer on the *by*-phrase for the reduced conditions (8b and 9b) than for the unreduced conditions (8a and 9a).

Just and Carpenter (1992), on the other hand, showed in (6) that high span readers processed the implausible conditions faster than the plausible conditions, but this effect was identical in the reduced (ambiguous) and unreduced (unambiguous) condition.

Furthermore, Waters and Caplan (1996) pointed out that the studies in Just and Carpenter (1992) were not presented with any statistical details that supported their conclusions.

Another main argument of Waters and Caplan (1996) is that there is evidence from neuropsychological research that is incompatible with the view that working memory performance on the span task directly relates to syntactic processing. These studies showed that various aspects of working memory, as measured by the span task, have no effect on sentence processing. As an example, Waters, Caplan, and Hildebrandt (1987) showed that patients with only a limited short-term memory (e. g. after a stroke) can still process various complex syntactic structures. In addition, Waters, Caplan, and Rochon (1995) showed that the syntactic processing of aphasic patients is unaffected when there is an additional digit load condition.

Just and Carpenter (1992) originally referred to the results of King and Just (1991) to argue that readers with a low capacity are more affected in their comprehension of object-relatives when there is an additional memory task than readers with high capacity span. In turn Waters and Caplan (1996) argued that such a claim should be supported by a three-way interaction between span group, sentence type and memory load. However, King and Just reported an interaction between span group and memory load and another interaction between sentence type and memory load, but they do not report the interaction necessary to support the claim that low spans are more affected by an additional memory load for syntactically complex structures than high span readers. Thus, Waters and Caplan argued that the claims made by Just and Carpenter is not actually supported by the findings reported in King and Just.

1.1.4 A neural network accounting for individual differences

Ericsson and Kintsch (1995) and MacDonald and Christiansen (2002) argued that the discussion about the effects of individual working memory capacity on cognitive performances ignores one essential aspect: *experience*. MacDonald and Christiansen agreed with Just and Carpenter (1992) that there is a correlation between language processing and working memory and there are individual differences in working memory which affects comprehension. However, the notion of *experience*, which is not considered in the constraint capacity approach, plays an integral role in the neural network model in MacDonald and Christiansen.

MacDonald and Christiansen (2002) described how a serial recurrent network (SRN) can model human sentence processing. For this they included a back-propagation algorithm in the SRN architecture that copied intermediate results back for the next simulation run. With this back-propagation, MacDonald and Christiansen argued, the network is able to learn and develop some form of memory and *experience*.

For the simulation of the Just and Carpenter (1992) sentences, MacDonald and Christiansen (2002) trained ten different serial recurrent networks to make predictions about the next incoming word in a sentence. The networks trained on corpora containing 10000 sentences. For each word, the networks *grammatical prediction error* (GPE) was determined. The sentences (10a, b) below were divided into four different interest areas. For each interest area the network returns a probability ranging from 0 to 1 predicting the next incoming word. This evaluation of the GPE of the network was done after the first, the second and after the third training. These different levels of training were meant to simulate readers with different experience of linguistic input.

10. (a) **subject-relative**
    The reporter that attacked the / senator / praised / the judge.

    (b) **object-relative**
    The reporter that the senator / attacked / praised / the judge.
    (Just & Carpenter, 1992, p. 140)

MacDonald and Christiansen (2002) compared the GPE for each interest area to the reading time pattern of Just and Carpenter (1992). Like in Just and Carpenter there were more errors in the object relative condition at the second (*attacked* in (10b) and at the third (*praised*) interest area than in the subject relative condition. Interestingly, these errors decreased with each evaluation run for the object relatives. MacDonald and Christiansen tested the networks' GPE after one training run, then after a second training and finally after the network was trained three times. The error rates decreased after each run for the object relative condition. Most interesting, the final error rate pattern is similar to the subject relative pattern, but the error rate at the critical region (*senator/attacked*) was still higher for the object-relative conditions after the third training. The error rates for subject relatives did not decrease.

Therefore, MacDonald and Christiansen (2002) reported that their network performed better (in the processing of object-relative sentences) for each of the consecutive runs. Thus, they argued that it might be readers' experience differences that cause individual differences in sentence processing. They claimed that readers' difference in reading performance of complex structures might stem from their previous exposure to such structures. Therefore, object-relatives may be harder for low-span readers because they haven't encountered them as often as high span readers have. Thus, even though MacDonald and Christiansen argued that the difficulty with object relatives is due to experience, it could also be understood as a frequency effect in sentence processing.

1.2 Models of structural complexity

1.2.1 Effects of locality in sentence processing

Models of locality are in line with the account that working memory affects sentence processing. They attempt to explain sentence processing difficulty in terms of the distance between heads and dependents. Gibson (1998) introduced the locality model of Syntactic Prediction Locality Theory SPLT, which was renamed the Dependency Locality Theory DLT in Gibson (2000). The locality theory claimed that there are two main processes that make comprehension difficult: (1) the **integration** of new items and (2) the storage of items in **memory** that need to be integrated with future items. Models of locality claim that understanding a sentence involves the step-by-step integration of new words into an existing sentence structure and the storage of words and phrases that have already been seen and are partially or fully integrated. While Just and Carpenter (1992) and Gibson (1998, 2000) agree that storage and integration costs are affected by working memory limitations, the DLT by Gibson (1998, 2000) directly quantified costs for working memory by describing *structural integration cost* and *simplified discourse processing cost*.

Structural integration cost modelled the difficulty for the integration of each word in the sentence. The discourse processing cost, on the other hand, described the storage energy consumed by each word in the sentence. An integration cost is associated with the number of discourse referents that are between a new to-be-integrated head and its already integrated dependent head. Gibson (2000) defined discourse referents as items that have a "spatiotemporal location". Thus, discourse referents are actually noun and verb phrases. One integration cost unit will be assigned for each discourse referent that is located between a head and its dependent. Additionally, if the current word is a discourse referent another integration unit will be assigned. Thus, for Example in (11), at the embedded verb *attacked*, 2 energy units (EU) will be assigned. 1EU because *attacked* is a discourse referent and 1EU because of the number of discourse referents that separate *attacked* from its dependent *who*. There is 1 discourse referent *senator* between *attacked* and *who* in Example (11).

11. **object-relative**
    The reporter who the senator attacked admitted the error.
    (Gibson, 1998, p. 2)

For the discourse processing or storage cost, 1 memory unit (MU) will be assigned at a word for each syntactic head that is necessary to grammatically complete the syntactic structure. For Example (11), at the very first word

The, 2MUs will be assigned because the parser needs to project at least one main noun and one main verb to finish the sentence.

Thus, by computing the cost for storage and integration at each word in the sentence, Gibson and the DLT attempted to predict sentence processing difficulty. Example (12) contrasts an embedded subject-relative with an object-relative clause. It is well known that embedded object-relatives in (12b) are harder to understand than embedded subject-relative clauses in (12a).

12. (a) **subject-relative**
    The reporter who attacked the senator admitted the error.

    (b) **object-relative**
    The reporter who the senator attacked admitted the error.

Table 1 shows the word-by-word energy and memory units for the subject and object relatives in (12a) and (12b). The table shows that at word 6, the integration of *saw* will cost 2EUs in contrast to only 1EU for the subject relative condition. There are 2EUs at position 6 for *attacked* because there is one discourse referent (*the senator*) that separates the verb *attacked* from its dependent *who* (that will be 1EU). In addition *attacked* is itself a discourse referent, which will cost another 1 EU. That together makes 2EUs for the integration of saw at position 6 in the object relative condition. There is only 1EU assigned to *janitor* at this position because *janitor* is a discourse referent but *janitor* is not separated from a dependent. The integration cost thus shows that object relatives claim more energy units at the end of the relative clause.

Memory cost showed a difference between object and subject relatives at position 4. There are 3MUs assigned for *the* whereas *attacked* at that position will cost only 2MUs. There are 3MUs for the article because at this position the parser needs to project three syntactic heads to finish the sentence: the embedded noun (*senator*), the embedded verb (*attacked*) and the main verb (*admitted*). In comparison, in the subject relative condition at the position of the embedded verb *attacked*, the parser only needs to project the embedded verb (*senator*) and the main verb *admitted*. Thus, the storage cost part of the DLT showed that the object relative will claim more memory units at the beginning of the relative clause.

Table 1: Moment-by-moment processing units according to the DLT

	1	2	3	4	5	6	7	8	9
Sr	The	reporter	who	attacked	the	senator	admitted	the	error.
EU	0	1	0	1	0	1	3	0	1
MU	2	1	3	2	2	1	1	1	0
Or	The	reporter	who	the	senator	attacked	admitted	the	error.
EU	0	1	0	0	1	2	3	0	1
MU	2	1	3	3	2	1	1	1	0

Thus, according to the DLT object-relatives are harder than subject relatives because heads and dependents get further separated in object relatives. This separation taxes memory because more discourse referents have to be projected for a longer time resulting in larger memory cost (see the predictions at the embedded *the* for object relatives) and dependents have to be integrated across longer distances resulting in larger integration costs.

Gibson (2000) described further support for locality effects from cross-linguistic studies. Babyonshev and Gibson (1999) presented an off-line rating study in Japanese. Readers were presented with double centre-embedded sentences. Centre-embedded structures are sentences where (like with English object relative clauses) heads and dependents get separated by a clause and heads and dependents of this intervening clause get separated by yet another clause. Example (13) shows an English sentence with two centre-embedded object-relative clauses. The relative clause *that the teacher saw* is centrally embedded within the relative clause *that the boy followed*, which is itself centrally embedded in the main clause *The girl left yesterday*. Thus, with the central embedding two relative clauses, the dependents *girl* and *boy* are separated from their respective heads $left_{girl}$ and $followed_{boy}$.

13. The girl | that the boy | that the teacher saw | followed | left yesterday.

Babyonshev and Gibson (1999) used centre-embedded clausal structures in Japanese in (14). The most embedded verb was either a transitive verb

(14a) (*ijimeta / bullied*) or an intransitive verb (14b) (*naita / cried*). The transitive verb *ijimeta* in the most central position in (14a) requires an object noun, while the intransitive verb *naita* in (14b) in the same position does not allow another object. Thus, the transitive condition in (14a) introduces another discourse referent which increases the distance between the two initial dependents *obasan-ga / aunt* and *bebiisitaa-ga / babysitter* and their respective heads *itta / said* and *omotteiru / thinks.* The DLT predicted that Japanese sentences with an embedded transitive verb in (14a) are more difficult than sentences with an embedded intransitive verb in (14b). Babyonshev and Gibson tested this using offline complexity rating.

14. (a) **embedded transitive verb**
    Obasan-ga | bebiisitaa-ga | ani-ga imooto-o ijimeta | to itta | to omotteiru.
    aunt NOM | babysitter NOM | older-brother NOM younger-sister ACC bullied | that said | that thinks.
    'My aunt thinks that the babysitter said that my older brother bullied my younger sister.'
    (Babyonshev & Gibson, 1999, p. 430)

    (b) **embedded intransitive verb**
    Obasan-ga | bebiisitaa-ga | ani-ga naita | to itta | to omotteiru.
    aunt NOM | babysitter NOM | older-brother NOM cried | that said | that thinks.
    'My aunt thinks that the babysitter said that my older brother cried.'
    (Babyonshev & Gibson, 1999, p. 431)

Babyonshev and Gibson (1999) showed that sentences like (14a) were indeed rated as more difficult than sentences like (14b). Thus, increasing the distance between heads and dependents seems to increase the comprehension difficulty for readers, which is what the DLT predicted.

1.2.2 Entropy reduction hypothesis

Hale (2006) introduced a measure of sentence processing difficulty that focussed on the information that a word in a sentence provides. His *entropy*

probability	rules				
`1.0`	`S`	$\rightarrow$	`N`	`RC`	`V`
`0.7`	`RC`	$\rightarrow$	`V`	`N`	
`0.3`	`RC`	$\rightarrow$	`N`	`V`	

Figure 1: Simple probabilistic context free grammar PCFG for relative clauses

reduction hypothesis claimed that the difficulty at a word is related to the amount of information that this word provides according to a probabilistic context-free grammar PCFG. A PCFG is a formal description of all possible sentences in a language that also provides the probability for phrase structure rules. Figure 1 shows a simple PCFG that consists of rules for sentences with two different kinds of relative clauses. The first column in Figure 1 gives the probability for each rule (e.g., `1.0` for a sentence `S`). In the example in Figure 1, a sentence `S` always consists of a `NP`, a `RC` and a `VP`. The `NP` will always be a noun N and the `VP` will always consist of a verb `V`. The relative clause, on the other hand, can have two different forms. The `0.7` indicates that 70% of all observed relative clauses will start with a verb phrase `VP` followed by a noun phrase `NP`. The `0.3` in front of the other rule determines that 30% of all relative clauses will start with a noun phrase `NP` and followed by the verb phrase `VP`. For a better understanding of these structures, the `0.7` probability rule describes a subject relative clause, whereas the 0.3 rule describes the probability and the structure of an object relative.

In addition, Hale (2006) described the uncertainty h (this uncertainty is measured in terms of bits) for each rule. Uncertainty is determined by using the probability for each rule. Equation 1 shows that the uncertainty h about the choice for a sentence `S` is 0, given the PCFG described in Table 1 because its probability is 1.0:

$$h_S = -1.0 \times log_2 1.0 = 0 \tag{1}$$

Thus, the more expected a rule the lower its uncertainty and the lower its processing cost.

The choice for a certain relative clause type on the other hand is less certain. Equation 2 shows how the uncertainty for the subject-relative clause is determined and Equation 3 computes the uncertainty for the object relative clause, given the the grammar in Figure 1.

$$h_{SR} = -0.7 \times log_2 0.7 = 0.36 \tag{2}$$

$$h_{OR} = -0.3 \times log_2 0.3 = 0.52 \tag{3}$$

Thus, the uncertainty of choosing the subject-relative is smaller than the object-relative. The results directly translate into the amount of bits of information provided by the structure. Consider the example (15a) and (15b) together with the simple grammar of Figure 1. The start holds no surprise: the sentence starts with the noun phrase `the butcher` (0 bits because there is no other possibility according to the grammar in 1). When the verb `loved` is encountered, it is clear that this is a subject-relative clause. The amount of information provided by `loved` in (15a) is 0.36 bits. The following noun phrase `the girl` does not hold any information (0 bits) since it is part of the subject-relative clause and there is no other possible structure. For the object-relative clause condition (15b), on the other hand, when the noun phrase `the girl` is encountered after the first noun phrase `the butcher`, it is clear that this is an object-relative clause. This provides 0.52 bits of information and has a higher processing cost than the information for a subject-relative clause.

15. (a) **subject-relative**
    The butcher who loved the girl left.

    (b) **object-relative**
    The butcher who the girl loved left.

This example shows how the entropy reduction hypothesis can account for the difficulty associated with object relatives. When the grammar indicates that an object-relative clause is less probable, the entropy (information) of a word that indicates an object-relative clause (*the girl*) is higher than the entropy for a word that indicates a subject-relative clause (*loved*) and higher entropy results in higher processing cost.

Hale (2006) argued that the entropy reduction hypothesis provides an explanation for other phenomena in sentence processing as well. He modelled the findings of Keenan and Hawkins (1987) who showed how comprehension difficulty may be related to the accessibility hierarchy (AH) of a relative pronoun in a sentence. The AH is also known as *syntactic rank* or *relational hierarchy* and provided a scale of how accessible an object is in the current discourse. Figure 2 shows the order for the role of such dependents in the AH. The hierarchy starts with the easiest argument role, which is the subject, followed by the object which ranks lower in the AH. The higher the argument role, the less costly the process.

$$\textit{subject} \supset \textit{dir. object} \supset \textit{indir. object} \supset \textit{oblique} \supset \textit{genitive} \supset \textit{ocomp}$$

(Hale, 2006, p. 651)

Figure 2: Accessibility hierarchy

Keenan and Hawkins (1987) tested the AH for sentences like (16a) to (16f), which contained relative clauses. The relative pronouns in these sentences varied in their grammatical roles: they either served as a subject (16a), a direct object (16b), an indirect object (16c), oblique (16d), a genitive subject (16e) or a genitive object (16f). The AH predicted that comprehension should be easiest for the subject-relative condition (16a), then the object-relative conditions (16b, 16c), followed by the oblique condition (16c) and then the genitive conditions (16e, 16f).

16. (a) **subject**
    I know that the girl | who got the right answer | is clever.

    (b) **direct object**
    I know that the dog | which Penny bought today | is very gentle.

    (c) **indirect object**
    I know that the man | who Steven explained the accident to | is kind.

(d) **oblique**
I know that the ship | which my uncle took Joe on | was interesting.

(e) **genitive subject**
I know that the boy | whose father sold the dog | is very sad.

(f) **genitive object**
I know that the woman | whose car Jenny sold | was very angry.
(Hale, 2006, p. 653)

In the comprehension experiment, repetition accuracy (Participants heard a sentence and after a short memory task they had to write down the memorised sentence. The repetition accuracy reflected how well the sentence was remembered.) followed the predictions made by the AH: the subject sentences (16a) had the highest accuracy scores and lowest error rates, followed by the direct object condition (16b), then the indirect object (16c) and finally the oblique conditions (16d). The genitive subject condition (16e) had lower accuracy scores and higher error rates than the genitive object condition (16f) contrary to the predictions of the AH. However, the results from the other conditions showed that the accessibility hierarchy predicted the recall difficulty (repetition accuracy). Keenan and Hawkins (1987) concluded that even though the AH correctly predicted error rates, it remains unclear why exactly relative clauses that are lower on the AH should be more difficult. Hale (2006) argued that the entropy reduction hypothesis might offer an explanation for this difficulty. Hale suggested that sentence processing involves the processing of information (entropy) of each incoming word and the comprehension becomes more difficult with an increasing amount of information associated with each word. Hale furthermore argues that the AH provided a scale for items and their provided information in a sentence. The entropy is expected to be higher for those syntactic roles that are lower on the AH because they are less accessible than those syntactic roles that are higher on the AH. Thus, for sentence sample (16a) to (16f) above, encountering a subject pronoun in (16a) (*who*) does not provide as much information as the encounter with a genitive object in (16f) (*whose*).

Applying two different PCFG grammars, Hale (2006) found a correlation between bits of information conveyed by the relative pronoun and the error score in one of the PCFG tested. The amount of information from the words corresponded to the accessibility hierarchy. Because a subject relative structure like in (16a) is more likely, the occurrence of a subjective pronoun *who* conveys less information about the sentence structure than the direct objects in (16b) (*who* might be ambiguous at this position because the indirect object condition also starts with *who*. However, since all other pronouns in (16) at this position are also ambiguous, *who* in the context of (16a) does indeed convey less information than the *which* in condition (16b).). Direct objects like in (16b), on the other hand, contain information about the syntactic role at this position less information than indirect objects in (16c), indirect objects less than the oblique in (16d) and the genitive cases in (16e, 16f) convey most information compared to the other conditions.

Thus, Hale (2006) has shown that if the encountered structure is less probable, the comprehension of the sentence becomes harder. The predictions made by the accessibility hierarchy corresponded to those made by the AH and also with the findings of Keenan and Hawkins (1987). To sum up, the findings of Hale suggest that the amount of information processed at a word correlates with the difficulty that is associated with that word and the ranking in the accessibility hierarchy.

1.2.3 A theory of *surprisal* in sentence processing

Levy (2007) introduced a model of sentence processing difficulty that models the expectation of the next word, known as *surprisal*. Surprisal has some similarity to the entropy reduction hypothesis advocated by Hale (2006) with the exception that surprisal does not describe the actual sentence structure. While Hale (2006) used probabilistic context free grammars to describe the structural interpretations of a sentence, Hale (2001) and Levy (2007) used probability distributions to rank possible sentence interpretations.

To illustrate the probability distribution over several interpretations of a sentence, consider example Sentence (17):

17. The defendant examined by the lawyer shocked the jury. (Just & Carpenter, 1992, p. 126-127)

Up until *by*, the sentence has two potential structural interpretations (the main clause interpretation and the reduced relative clause interpretation), see Table 2.

Table 2: Interpretations of Example (17) structure before the main verb *found*.

1. 0.8	The defendant examined ....
2. 0.2	The defendant [(that was) examined by the lawyer] ....

In Table 2 each interpretation has a probability: (1.) 0.8 for the first main clause interpretation and (2.) 0.2 for the second relative clause interpretation. In sentence (17), the main clause interpretation is preferred with a probability of 0.8 before the preposition *by* is encountered. In order to integrate *by*, the table has to be re-ranked and the formerly less preferred structure, the reduced relative clause, has to become the higher ranked interpretation. This re-ranking is costly and it is particularly even more costly because the probability for the relative clause interpretation is so much smaller (0.2) than the probability for the main clause interpretation (0.8). Thus, surprisal of Levy (2007) can account for the difficulty associated with relative clause structures (subject relatives here) like in example (17). In addition, surprisal makes the prediction that this difficulty will be observed at the point when the preposition *by* will be integrated into the sentence. The Table 2 will have to be reranked when *by* is encountered. Evidence for surprisal will be described and discussed in the following chapters.

1.2.4 Expectation of upcoming material

Konieczny (2000) provided evidence for surprisal from the verb-final language German. Verb-final languages allow the verb (for some constructions) to come after its arguments. Consider example (18):

18. Der Reporter hat den Professor getroffen.
    The reporter - has - the - professor - met
    The reporter has met the professor.

The verb *getroffen* (*met*) is the head of the sentence. Its dependents *Reporter* (*reporter*) and *Professor* (*professor*) precede the head. Thus, the two dependents will have to be stored in memory or kept active until they can be integrated with the head. Verb-final structures like these are common in German. Levy (2007) argues that these structures have implications for surprisal: during the processing of the two noun phrases (*Reporter* and *Professor*) their main verb, which is the sentence head, is predicted. The prediction of the verb becomes stronger with every word that is encountered after the first noun phrase. Levy (2007) claimed that since a main verb is needed for a sentence, the likelihood that the verb occurs, rises with each interfering word. Therefore the longer it takes to get to the main verb the higher the prediction of the main verb.

Thus, the theory of surprisal predicted that the integration of *getroffen* should become easier with every noun phrase that precedes the verb, since the expectation of the appearance of the verb rises. This is an important difference to the locality account (Gibson, 1998). The structural integration cost of the DLT predicted that the integration of the head verb becomes harder the longer the distance (the distance is measured in terms of discourse referents) from its dependents. Therefore, the DLT predicted that the integration of *getroffen*(*met*) should be hard because there is one discourse referent *Professor* (*professor*) between the verb and its subject *Reporter* (*reporter*). Surprisal, on the other hand, predicted that the high anticipation of the main verb *getroffen / met* after a long interfering region (such as *hat den Professor / has the professor* in (18)) should make its integration easy.

Konieczny (2000) investigated sentences such as (19). The sentences in Example (19) present a relative clause in (19a) which is *adjacent* to the head *die Rose* and *extra-posed* in (19b) after the main clause. Locality predicted that the adjacent condition (19a) is harder than the extra-posed condition. The main verb *hingelegt / laid_down* is separated by the intervening relative clause in (19a) and thus the integration of *die Rose* with *hingelegt /*

laid_down should be harder in (19a) than in (19b), according to models of locality. Surprisal, on the other hand, predicts that *hingelegt/laid_down* will be integrated more quickly in the adjacent condition (19a) than in the extra-posed condition (19b) because the expectation of the main verb rises during the processing of the relative clause.

Konieczny (2000) conducted an off-line acceptability judgement experiment and an online self-paced reading experiment testing sentences like the examples in (19). The sentence was presented either in the adjacent (19a) or the extra-posed (19b) condition. The distance between the subject *Rose / rose* and the main verb *hingelegt / laid_down* in the adjacent condition and between the subject and the relative clause is one word.

The DLT predicted that the adjacent conditions (19a) should be more difficult than the extra-posed conditions (19b).

19. He laid down the rose that was beautiful.

    (a) **adjacent: RC$_1$**
    Er hat die Rose, <u>die wunderschön war</u>, *hingelegt*.
    (He - has - the - rose - that - beautiful - was - laid_down.)

    (b) **extra-posed: RC$_2$**
    Er hat die Rose *hingelegt*, <u>die wunderschön war</u>.
    (He - has - the - rose - laid_down - that - beautiful - was.)
    (Konieczny, 2000, p. 632)

The offline judgements and the reading times showed that the adjacent conditions (19a) were rated more acceptable than the extra posed conditions (19b), which is not compatible with a locality account. Reading times were faster at the main verb *hingelegt / laid_down* in the adjacent condition (19a) than in the extra-posed condition (19b). These findings pose a challenge for the DLT which assumed that the integration of the verb should be harder in the adjacent conditions. Levy (2007) argued that the findings reported in Konieczny (2000) are more in accordance with surprisal. Since the findings of

Konieczny are not in agreement with locality, Levy argued that the DLT might not apply to languages other than English, suggesting a model that would combine surprisal and locality. In such a model surprisal could account for effects in verb-final structures like German, whereas locality explains memory effects in structures that are not verb-final, like English.

1.3 Direct comparison of surprisal and DLT

1.3.1 Locality in self-paced reading

Models of sentence processing like the discourse locality theory (DLT) and models of surprisal predicted that embedded object relative clauses are harder than embedded subject relative clauses. However, they make different predictions about where the effect should occur. While locality predicted that the difficulty should occur at the embedded verb of the object relative, surprisal claimed that the difficulty occurs early at the position of the embedded noun in object relatives (In subject relatives the embedded verb is at a different position in comparison to object relatives. Thus, the longer reading times in object relatives are at the noun when the verb was expected to occur).

Grodner and Gibson (2005) conducted a self-paced reading experiment that contrasted embedded object- with subject-relative clauses to test predictions made by locality and surprisal. Previous studies, like King and Just (1991) and Gordon et al. (2001), have shown longer reading times for the region containing the embedded verb in the object-relative condition compared to the region containing the verb in the subject-relative condition. However, Grodner and Gibson argued that the design of these studies was not appropriate to distinguish between effects of locality and surprisal. Gordon et al. presented each word in the centre of the screen, which, according to Grodner and Gibson, is not a natural presentation and might have caused inflated reading times at each word. Therefore, the self-paced reading experiment by Grodner and Gibson presented sentences in a non-cumulative and self-paced way. To avoid that effects of the embedded verb *sent* will spillover and be observed at the main verb *hoped* in the object-relative condition (20b), a prepositional phrase *to the editor* was included to separate both verbs. Surprisal predicted that increased reading time should occur at the subject of the embedded object relative clause (*the photographer*) in 20b. Most commonly, a subject relative like (20a) would be predicted after the relative pronoun (*who*) and thus an embedded verb (like *sent*) is expected to appear next. The appearance of *the photographer* in (20b) is unexpected and therefore, according to surprisal, its integration is difficult. Once *the photographer* is integrated in (20b), the prediction of the embedded verb is higher than it was before encountering *the photographer*. Therefore, the integration of *sent* after *the photographer* in (20b) should be easier than the integration of *sent* before *the photographer* in (20a).

The DLT, on the other hand, predicted that object relatives should be harder than subject relatives because of the distance between the embedded verb *sent* in the object relative condition in (20b) and its dependent *that*. This difficulty should be observed during the integration of the embedded verb *sent* in (20b). (It should be noted that Grodner and Gibson (2005) focused on the integration cost of the DLT and do not give a discussion about the prediction of the memory cost aspect of the DLT.) Thus, there should be longer reading time at the embedded verb *sent* in (20b) than at *photographer* in (20a).

20. (a) **subject-relative**
    The reporter | who | sent | the photographer | to the editor | hoped for a good story.

    (b) **object-relative**
    The reporter | who | the photographer | sent | to the editor | hoped for a good story.
    (Grodner & Gibson, 2005, p. 269)

Grodner, Waters, and Gibson (2000) reported that the embedded verb *sent* was read slower for the object-relative condition in (20b) than the subject-relative condition in (20a). There was no increased reading time observed at the embedded subject *the photographer* of the object relative clause (20b). These findings are in agreement with the predictions made by the locality account DLT. The findings were not in agreement with any of the predictions made by surprisal. Thus, using self-paced reading, Grodner et al. (2000) presented findings that support an account of locality in sentence processing.

1.3.2 Expectation with maze task

In addition to eye-tracking, grammaticality judgements and self-paced reading tasks, Forster, Guerrera, and Elliot (2009) investigated whether the maze task could be a sensitive measure of syntactic complexity. The maze task is an online sentence comprehension task where at each word, the reader has to make a decision about how to continue the sentence fragment that was seen so far. For example, after the presentation of an initial article *The*, two words (*banker*, *amazes*) are presented and the participant has to decide whether the sentence can continue with *banker* or with *amazes*. After the article *The*, *banker* would be the correct choice to continue the sentence, since *amazes* would not be a grammatical fit after *The*. For each following word, the participant has to make a decision which one of two alternative words would be the grammatical continuation of a previous sentence segment. Forster et al. argued that the maze task, in contrast to the self-paced reading paradigm, forces the reader to fully integrate the word into the sentence structure before the next word could be considered. Thus, according to Forster et al., the maze task should avoid effects of spillover from previous regions.

Forster et al. (2009) used the maze task to investigate whether it can reflect typical sentence comprehension processes. As an example, the maze task could investigate the difficulty of object relatives in comparison with subject relatives. If the maze task is indeed sensitive to sentence complexity effects, there should be longer decision times in the object relative condition in (21b) than in the subject relative condition in (21a).

21. (a) **subject-relative**
    The banker that irritated the lawyer played tennis every weekend.

    (b) **object-relative**
    The banker that the lawyer irritated played tennis every weekend.

The results showed that object relatives (21b) had longer decision times than subject relatives (21a). This difference was especially pronounced at the article of the embedded noun phrase *the*. Forster et al. (2009) argued that prior experiments had failed to show this, since the difference between object and subject relatives was always collapsed over the whole relative clause. This early difficulty for the object relative clause, according to Forster et al., is more in agreement with surprisal (Hale, 2006; Levy, 2007) than with accounts of locality (Gibson, 1998, 2000).

However, the argument of Forster et al. (2009) that his findings support surprisal might be circular. Forster et al. initially designed this experiment to test whether the maze task could reflect difficulty during sentence comprehension. In order to test the maze task, object and subject relatives were used since the phenomenon of a difficult object relative clause in contrast to an easier subject relative condition is well researched. Forster et al. could indeed show that object relatives had longer reaction times than subject relatives, which is in agreement with previous findings. However, the decision times differed especially at the article of the embedded noun phrase (*the lawyer*). Forster et al. interpreted this finding to be more in agreement with surprisal, but it might well be a consequence of the maze task. Forster et al. initially tested whether the maze task could indeed reflect sentence comprehension processes. The findings using the maze task might indicate an effect of surprisal. However, Forster et al. should also consider that the maze task does not reflect online comprehension processes (making a decision about the grammaticality of an input might be disruptive). My point is that by investigating whether the maze task could reflect comprehension processes and at the same time claiming that the findings support a surprisal approach, Forster et al. might have skipped a step.

1.3.3 Contrasting locality and expectation effects using eye-tracking

Staub (2010) argued that eye-tracking, unlike the maze task or self-paced reading, provides measures that capture different aspects of the reading behaviour and might be more suitable to investigate the time-course of sentence comprehension processes.

In order to differentiate between effects of surprisal and locality like the DLT, an eye-tracking experiment was conducted and each word of the relative clause as well as the main verb was analysed as an area of interest (the areas of interest are indicated in the materials of (22a) and (22b)). The DLT predicted that difficulty should be observed at the embedded verb *noticed* in (22b), while surprisal claims that difficulty should be observed early at the noun phrase *the fireman* (22b). Both accounts, however, expected that the object-relative condition (22b) should be harder than the subject-relative condition (22a).

22. (a) **subject-relative**
    The employees | that | noticed | the | fireman | hurried | across the open field.

    (b) **object-relative**
    The employees | that | the | fireman | noticed | hurried | across the open field.
    (Staub, 2010, p. 75)

Staub (2010) reported two important findings from the eye-tracking experiment. First, the difficulty for object relatives was observed early in the relative clause: the number of regressions was higher at every word in the object-relative clause than the subject-relative clause. The finding that the difficulty was observed early at the first word of the relative clause is consistent with the predictions of surprisal. Second, the reading time measures (*first fixation duration*: duration of first fixation on a word, *gaze duration*: is the sum of all first-pass fixations and *go-past time*: is the sum of all fixations on a region when the region is fixated for the first time until the reader leaves the word to the right. These include re-fixations to regions to the left.) showed that the embedded verb (*noticed*) in the object relative clause took longer to read than in the subject-relative clause. Thus, the first finding seems to support the surprisal account, while the second finding in the reading times is more in agreement with the DLT. Thus, evidence for surprisal and the DLT was observed in different reading measures. Evidence for surprisal was observed in terms of regressive saccades, evidence for locality was observed in reading time measures. Staub (2010) suggested that these observations might be caused by different processes: parsing failure causing the surprisal effect at the object-relative subject and a memory retrieval effect causing the locality effect at the verb of the object-relative clause.

1.3.4 How could locality and surprisal be combined?

The DLT quantified memory costs during online sentence processing. While Gibson (1998, 2000) presented evidence in favour of locality effects using the English language, Babyonshev and Gibson (1999) presented findings that showed effects of locality for Japanese sentences. However, the latter was an offline rating study and may not reflect the online word-by-word memory demands that the DLT predicts.

Vasishth and Drenhaus (2011) investigated online effects of locality in German using self-paced reading, eye-tracking and event-related potentials (ERP). Contrasting sentences that contained an extracted relative clause, Vasishth and Drenhaus (2011) manipulated the distance between the relative clause verb *ignoriert / ignored* and its dependent *Direktor / director* in (23). Accounts of locality, like the DLT, predicted that the longer the distance between the verb (*ignoriert / ignored*) and its dependent (*Direktor / director*), the more difficult the integration at the verb. Thus, the long distance condition (23c) will have longer reading times at the verb *ignoriert hatten / ignored had* than the short distance and medium distance conditions (23a) and (23b). Interestingly, accounts of anti-locality, like surprisal, predicted the opposite results for sentences like 23. The expectation of the verb of the extracted relative clause rises with each intervening item, therefore *ignoriert hatten / ignored had* is highly predicted and should be easier to integrate in (23c) than in (23b), which in turn should be easier than in (23a).

23. (a) **short distance**
    Die Mutter von Paula und die Schwester von Sophie gruessten den **Direktor**, den Maria und Franziska **ignoriert** hatten.

(The mother of Paula and the sister of Sophie greeted the director whom Maria and Franziska ignored had.)

(b) **medium distance**
Paula und die Schwester von Sophie gruessten den **Direktor**, den Maria und die Mutter von Franziska **ignoriert** hatten.
(Paula and the sister of Sophie greeted the director whom Maria and the mother of Franziska ignored had.)

(c) **long distance**
Paula und Sophie gruessten den **Direktor**, den die Schwester von Maria und die Mutter von Franziska **ignoriert** hatten.
(Paula and Sophie greeted the director whom the sister of Maria and the mother of Franziska ignored had.)
(Vasishth & Drenhaus, 2011, p. 62)

For the self-paced experiment, reading times on the last three words *Franziska ignoriert hatten / Franziska ignored had* were analysed. Condition (23c) had the longest reading times on all three words, followed by (23b) (the difference between (23b) and (23c) was significant for *Franziska* and *hatten / had*, but not for the critical word *ignoriert / ignored*) and (23a) had the shortest reading times for all three words. These findings are in agreement with locality but not with surprisal.

For the eye-tracking experiment, Vasishth and Drenhaus (2011) reported an effect at the pre-critical region at *Franziska*: (23c) had a lower first-pass regression probability than (23b) at the pre-critical region. Furthermore, the re-reading probabilities at the post-critical region (*hatten / had*) were higher in (23b) and (23c) in comparison with (23a). Re-reading probability was higher for (23b) than (23c) in the post-critical condition (*hatten / had*). While the re-reading probability findings supported locality, the lower regression in the early first-pass measure is more consistent with surprisal.

In the ERP study, the time window after the critical verb (*ignoriert / ignored*) showed a negativity in the 300-500ms window for the contrast (23b) and (23c) versus (23a). The complex conditions (23b) and (23c) were more negative than (23a). Vasishth and Drenhaus (2011) argued that this negative effect is associated with a *long-distance dependency resolution* as reported by Kluender and Kutas (1993). Thus, this effect is more in accordance with locality.

In all three German experiments, the authors find effects in support of locality. However, the early regression effect found in the eye tracking experiment supported an expectation-based account.

These findings are similar to those reported by Staub (2010) who also reported surprisal effects in regressive measures and locality effects in reading time using eye-tracking for English sentences. Vasishth and Drenhaus (2011) argued that these results indicate that expectation is not an alternative to memory-based accounts like locality. Effects of expectation can be observed during sentence processing insofar as they constrain sentence processing in addition to effects of memory (like the DLT).

1.4 Alternative explanations for the relative clause effect

Besides accounts of locality (DLT), anti-locality (*expectation* and *surprisal*), there are alternative models that explain why object relative clauses are harder than subject relative clauses.

1.4.1 Perspective shift

The perspective shift approach by MacWhinney (1982) and MacWhinney and Pleh (1988) explained that the difficulty of object relatives is due to an increased number of perspective shifts a reader has to perform in order to comprehend them. For example in sentence (24a), the perspective is that *the dog* is the subject for the main and the relative clause. Thus, no perspective shift is necessary for the subject relative condition in (24a). In (24b), the perspective that *the dog* is the subject will have to be changed or shifted when *the cat* is encountered after the relative pronoun *that* because *the cat* is the subject in the object relative clause. The perspective that *the cat* is the subject will again have to change after the relative clause when *the dog* turns out to be the subject of *kicked*.

24. (a) **subject-relative / SS**
The dog that chased the cat kicked the horse.

(b) **object-relative / SO**
The dog that the cat chased kicked the horse.
(MacWhinney, 1982, p. 26)

MacWhinney (1982) argued that since there are two perspective shifts for the processing of the object-relative sentence and no perspective shifts for the subject-relatives, object relatives are more difficult to process than subject relative conditions.

1.4.2 The active filler strategy

The active filler strategy AFS by Frazier and Clifton (1989) is part of the garden-path theory described by Frazier (1979) and is another model that explains why object relatives are harder than subject relatives. Originally, the garden-path theory was formulated to account for the difficulty observed during the processing of sentences that contain a local ambiguity. Consider the example sentence: *The horse raced past the barn fell.* Processing this sentence, readers initially interpret *raced* as the main verb of the sentence. When *fell* is encountered, this verb does not fit into the sentence structure built so far. In order to integrate it, the reader has to reanalyse the interpretation of the sentence and interpret *raced* as a verb that is embedded in a reduced relative clause and *fell* as the main verb. Frazier described two principles that determine the processing difficulty for sentences with a local ambiguity: Minimal attachment and late closure. According to minimal attachment, at each point in the sentence, the parser postulates the minimal number of nodes to finish the current structure grammatically. Because of minimal attachment, readers assume that *raced* is the main verb in the above sentence. A sentence like *The horse raced past the barn.* has fewer grammatical nodes than a sentence with a relative clause. Late closure claims that the parser automatically integrates each incoming word with the items that are lower in the tree structure which is usually more recent. This means that if an item has several potential attachment points in the sentence it will be attached to the node that is nearer.

The garden-path theory not only accounts for the difficulty observed with sentences with a local ambiguity, Frazier and Clifton (1989) argued that it can also account for the relative clause difficulty. In addition to minimal attachment and late closure, the theory assumes a third strategy: the active filler strategy (AFS). During relative clause processing, the parser identifies *that* as a filler for a gap in (25) and projects a phrase of the filler category at the earliest potential gap position (e_i indicates potential gap position in (25)). This explained the difference in processing cost for subject and object relative clauses.

The filler *that* in (25) is ambiguous and readers postulate the gap as soon as possible. In subject relatives like (25a), the gap will be immediately postulated after *that* and the projection of *the lawyer* will take the subject position of the relative clause. In object relatives like (25b), however, when *that* is identified as a filler for a gap, *the lawyer* cannot take the subject position of the relative clause, since this role is already filled by *the banker*. According to AFS a reanalysis effect occurs at the position of the embedded noun *the banker* in the object relative condition (25b). Subsequently, in (25b) the gap has to be postulated after the embedded verb *irritated*.

25. (a) **subject-relative**
    The lawyer $that_i$ irritated the banker filed a hefty lawsuit.

    (b) **object-relative**
    The lawyer $that_i$ the banker irritated e_i filed a hefty lawsuit.
    (Traxler et al., 2002, p. 73)

However, findings presented by Staub (2010) were not in agreement with the AFS. In an eye-tracking experiment, Staub presented object relatives with (26a) or without (26b) the relative pronoun (*that*). Staub argued that the AFS predicted that object-relatives without the relative pronoun (*that* in 26b) should be easier than object relatives with the relative pronoun (*that* in 26a). The filler (*that*) is missing in (26b); thus, the AFS could not erroneously postulate a subject gap after *that*. There is no ambiguity and thus no reanalysis required at *the fireman* in (26a). Therefore, AFS predicts that (26b) should be easier than (26a).

26. (a) **present relative pronoun**
    The employees that the fireman noticed hurried across the open field.

    (b) **absent relative pronoun**
    The employees the fireman noticed hurried across the open field. (Staub, 2010, p. 79)

Go-past time and regression rates at the embedded subject (*the fireman*) showed that the absent relative pronoun condition (26b) was harder than the present relative pronoun condition (26a). This finding is in the opposite direction to the prediction of the AFS. This supports expectation-based accounts which predict that a relative pronoun indicates a following relative clause and thus the expectation of a relative clause rises. An expected relative clause is easier to process than an unexpected relative clause. Therefore, the finding that the absent relative pronoun condition (26b) was harder than the present relative pronoun condition is in agreement with expectation based accounts from Hale (2006) and Levy (2007).

1.4.3 The role of animacy and the topicality for relative clauses

Using eye-tracking, Traxler et al. (2002) and Traxler et al. (2005) investigated how the animacy of noun phrases in memory affects relative clause comprehension.

Traxler et al. (2002) conducted an eye-tracking experiment to contrast effects of memory-load during the processing of object and subject relatives. In addition to the comparison of the relative clause type, the animacy of the noun phrases was manipulated. Embedded subject relatives were compared with embedded object relatives when the sentence subject noun was either animate (*director* and the embedded noun was inanimate *movie* in (27a, 27b)) or the sentence subject was inanimate (while the embedded noun was animate in (27c, 27d)).

27. (a) **subject-relative / animate subject**
The director that watched the movie received a prize at the film festival.
(b) **object-relative / animate subject**
The director that the movie pleased received a prize at the film festival.
(c) **subject-relative / inanimate subject**
The movie that pleased the director received a prize at the film festival.
(d) **object-relative / inanimate subject**
The movie that the director watched received a prize at the film festival.
(Traxler et al., 2002, p. 79)

Traxler et al. (2002) reported a main effect of relative clause type, with longer reading times in the object relative condition than in the subject relative condition. More importantly, Traxler et al. reported an interaction effect, object relatives with an animate subject noun (27b) took longer to read than object relatives with an inanimate subject noun (27d). The difference between the conditions with an animate subject and an inanimate subject in the subject relative conditions was not significant.

Investigating the influence of semantic information on syntactic processing, the materials in (27) contrasted conditions where animacy either supported the correct syntactic interpretation or interfered with it. The predictions are similar to the previous experiment of Traxler et al. (2002): inanimate noun phrases are poor agents and therefore not very likely subjects of sentences. Thus, if semantic factors affect syntactic processing, Traxler et al. (2005) predicted that conditions with an animate noun as the subject of the relative clause (28a,d) should be easier than conditions with an inanimate noun as the subject of the relative clause (28b,c). Thus, in addition to the memory load (caused by the relative clause), Traxler et al. predicted that the animacy of the embedded subject (28b,28c) should add to the processing difficulty. Traxler et al. tested these predictions in an eye-tracking experiment contrasting object- (28b, 28d) with subject-relative clauses (28a, 28c) with embedded subjects that were either animate (28a, 28d) or inanimate (28b, 28c).

28. (a) **subject-relative / animate rc subject**
    The musician that witnessed the accident phoned the police.

    (b) **object-relative / inanimate rc subject**
    The musician that the accident frightened phoned the police.

    (c) **subject-relative / inanimate rc subject**
    The accident that frightened the musician caused a lot of injuries.

    (d) **object-relative / animate rc subject**
    The accident that the musician witnessed caused a lot of injuries.
    (Traxler et al., 2005, p. 211)

Traxler et al. (2005) reported an interaction between animacy and relative clause type: object-relatives were harder than subject-relatives and this difference was more pronounced for object relatives that had an embedded inanimate subject (28b) than for object relatives that had an embedded animate subject (28a). The difference between the two subject relative conditions (with animate relative clause subject and an inanimate relative clause subject) was not significant. These finding are similar to the results presented in Traxler et al. (2002). Accounts of locality cannot explain this interaction, because they predict that object relatives should be harder than subject relatives and this should be unaffected by the animacy of the noun in the relative clause.

The results of Traxler et al. (2002, 2005) suggested that animate noun phrases make better subjects than inanimate noun phrases. While Traxler et al. (2002) tested the animacy effect of the sentence subject, Traxler et al. (2005) tested the animacy of the embedded subject. The findings of Traxler et al. (2005) have shown that having an inanimate subject noun phrase and an embedded animate noun phrase can reduce the processing difficulty of object relative clauses. Mak et al. (2002) and Mak et al. (2006) claimed that, in addition to animacy, the topicality of the antecedent of the relative pronoun affects relative clause processing. The findings about the animacy of the sentence subject and the relative clause subject is related to the *topichood hypothesis*, which is another account to explain relative clause difficulty. A basic assumption of the topicality account is that a relative clause describes something about a previously introduced item. Thus, this previously introduced item is actually the *topic* of the relative clause. In: *The girl that sees the boy left.*, *girl* is the topic of the relative clause *that sees the boy*. Generally, the subject of a sentence coincides with also being the sentence topic. Readers' preference to choose an entity as the subject of the relative clause is determined by the *topicworthiness* of that entity. The topic of the relative clause is a more likely candidate to be its subject than its internal noun phrase *the boy*. In a subject relative clause the topic of the relative clause (*girl*) is also the subject of the relative clause. In contrast, the object relative has its own internal noun phrase (*boy*) which is the subject of the object relative clause. Thus, Mak et al. (2002) and Mak et al. (2006) described how the *topic-worthiness* of a candidate can determine its eligibility as a subject of a relative clause and thus ease of comprehension. Since the internal noun phrase *the boy* is less topic-worthy as the subject of the relative clause than *the girl*, object relatives sentences like *The girl that the boy sees left* are harder than subject relative sentences *The girl that sees the boy left.*

According to Mak et al. (2002) and Mak et al. (2006), the animacy of a noun phrase should be considered as a factor when the topic-worthiness of an entity is assessed. Animate noun phrases are more topic-worthy than in-animates. Furthermore, an entity that is the discourse topic is a more likely candidate for the subject position in the relative clause than one that is not the discourse topic.

Mak et al. (2002) investigated the role of animacy in relative clause processing in Dutch. In Dutch, object- and subject-relative clauses have the same word order, the ambiguity whether the clause is object- or subject-relative is resolved at the auxiliary (*heft / hebben* in (29)). In (29) before the auxiliary *heft / hebben* is encountered the clause could be either, object-relative (who the students met) or subject-relative (who met the students). In (29a) *heeft* disambiguates it as a subject-relative clause and in (29b) *hebben* makes it an object-relative clause.

29. (a) **subject-relative**

    Morgen zal de professor, die de studenten ontmoet heeft, de diploma's uitreiken.

    (Tomorrow will the professor, that the students met has, the diplomas present.)

    Tomorrow the professor, who has met the students, will present the diplomas.

    (b) **object-relative**

    Morgen zal de professor, die de studenten ontmoet hebben, de diploma's uitreiken.

    (Tomorrow will the professor, that the students met have, the diplomas present.)

    Tomorrow the professor, whom the students have met, will present the diplomas.

    (Mak et al., 2002, p. 50)

Example (30) show the materials that were presented in a self-paced reading and in an eye-tracking experiment. (In the eye-tracking experiment, the materials were presented with an additional prepositional phrase *in het weekend / over the weekend*). Mak et al. (2002) contrasted object- (30b, 30d) with subject-relative conditions (30a, 30c) where the embedded object noun phrase was either an animate (30a, 30b) or an inanimate noun (30c, 30d). In Dutch, the embedded auxiliary disambiguates the type of relative clause. Thus, before the auxiliary (*hebben / have*) is encountered in (30), the relative clause could either be a subject- or an object-relative. The auxiliary is always plural in (30). Since one of the two noun phrases of the relative clause is plural, *hebben / have* determines that this plural noun phrase will be the subject of the relative clause. Thus, (30a) contains a subject-relative clause because the plural *inbrekers / burglars* agrees with the plural auxiliary *hebben / have*. In addition, Mak et al. (2002) manipulated the animacy of the noun phrases of the relative clause. The object of the subject-relative (30c) and the object-relative condition (30d) was inanimate in contrast to that the object of the subject-relative (30a) and the object-relative condition (30b) was animate. Mak et al. (2002) assumed that the animacy of the noun phrase should help in the assignment of the object- and subject-relative roles. Therefore, Mak et al. (2002) predicted that conditions with an embedded inanimate object (30c) and (30d) should be easier than those with an embedded animate object (30a) and (30b).

30. (a) **subject relative / animate object**
    Vanwege het onderzoek moeten de inbrekers, die de bewoner beroofd hebben.
    (in het weekend), nog een tijdje op het politiebureau blijven.
    (Because of the investigation must the burglars, who the occupant robbed have, some time stay at the police station.)
    Because of the investigation, the burglars, who robbed the occupant, had to stay at the police station for some time.

    (b) **object relative / animate object**
    Vanwege het onderzoek moet de bewoner, die de inbrekers beroofd hebben.
    (in het weekend), nog een tijdje op het politiebureau blijven.
    (Because of the investigation must the occupant, who the burglars robbed have, some time stay at the police station.)
    Because of the investigation, the occupants, who the burglars robbed, had to stay at the police station for some time.

    (c) **subject relative / inanimate object**
    Vanwege het onderzoek moeten de inbrekers, die de computer gestolen hebben.
    (in het weekend), nog een tijdje op het politiebureau blijven.
    (Because of the investigation must the burglars, who the computer stolen have, some time stay at the police station.)
    Because of the investigation, the burglars, who stole the computer, had to stay at the police station for some time.

    (d) **object relative / inanimate object**
    Vanwege het onderzoek moet de computer, die de inbrekers gestolen

hebben.
(in het weekend), nog een tijdje op het politiebureau blijven.
(Because of the investigation must the computer, that the burglars stolen have, some time stay at the police station.)
Because of the investigation, the computer, that the burglars stole, had to remain at the police station for some time.
(Mak et al., 2002, p. 56)

The reading times in the self-paced reading times showed that the auxiliary (*hebben / have*) was read significantly slower when the embedded object was animate (30a, 30b) in contrast to when the embedded object was inanimate (30c, 30d). Interestingly, there was no difference between the object and subject relative conditions for the embedded inanimate object condition (30c and 30d). The reading measures of the eye tracking experiment reflected the findings of the self-paced reading experiment. Object-relatives (30b) had longer reading times than subject relatives (30a) when the embedded object was an animate noun phrase. Most importantly, there was no difference between the relative clause types when the embedded noun phrase was inanimate. Thus, Mak et al. (2002) showed that readers use the animacy as a cue during the parsing of complex structures. For relative clauses in Dutch, embedding an inanimate object can even eliminate the difference between object- and subject relative clauses.

Mak et al. (2006) designed a self-paced and an eye-tracking experiment to contrast whether an animate or an inanimate noun is the preferred subject of the relative clause in Dutch. Mak et al. contrast object and subject-relative sentences in Dutch. Similar to the materials in Mak et al. (2002), Example (31) contrasted embedded animate noun phrases with inanimate noun phrases and just like in Mak et al. (2002) the animacy of the embedded noun phrases disambiguated the relative clause. For example in (31a), *die de rots weggerold hebben* might be interpreted as: 1) *that have rolled away the rock* or 2) *that the rocks have rolled away.* Since *the rocks* are inanimate, the first interpretation is the correct interpretation of the relative clause in (31a).

31. (a) **subject relative / animate subject**
    In het dorp zijn de wandelaars, die de rots weggerold hebben, het gesprek van de dag.
    (In the town are the hikers, that the rock rolled-away have, the talk of the day.)
    In the town the hikers, that have rolled away the rock, are the talk of the day.

    (b) **object relative / animate subject**
    In het dorp is de rots, die de wandelaars weggerold hebben, het gesprek van de dag.
    (In the town is the rock, that the hikers rolled-away have, the talk of the day.)
    In the town the rock, that the hikers have rolled away, is the talk of the day.

    (c) **subject relative / inanimate subject**
    In het dorp is de rots, die de wandelaars verpletterd heeft, het gesprek van de dag.
    (In the town is the rock, that the hikers crushed has, the talk of the day.)
    In the town the rock, that has crushed the hikers, is the talk of the day.

    (d) **object relative / inanimate subject**
    In het dorp zijn de wandelaars, die de rots verpletterd heeft, het gesprek van de dag.
    (In the town are the hikers, that the rock crushed has, the talk of the day.)
    In the town the hikers, that the rock has crushed, are the talk of the day.
    (Mak et al., 2006, p. 473)

Both experiments showed an interaction between relative clause type and subject animacy. Object-relatives with an embedded inanimate subject were read slower than object relatives with an embedded animate subject noun.

There was no difference between object and subject relative conditions when the subject of the relative clause was animate and the object of the relative inanimate. When the subject was inanimate and the object animate in the relative clause, the object relative conditions were harder. This effect was observed at the auxiliary and the following words.

These findings are in agreement with the topicality account. Readers prefer the topic of the sentence to be the subject of the relative clause. Furthermore, they prefer an animate noun phrase at the subject position over an inanimate.

More evidence supporting the topicality account is presented by Mak, Vonk, and Schriefers (2008). In a first self-paced reading experiment, Mak et al. (2008) tested the topichood of the relative clause internal noun and pronoun in object- and subject-relative clause sentences in (32). In this experiment, the role of the embedded noun phrase (*wandelaars*) was ambiguous until the auxiliary (*heft/hebben*) would make it clear that *wandelaars* was either the subject (32a) or the object (32b) of the embedded clause. Furthermore, Mak et al. (2008) tested the role of embedded pronouns (*jullie*), here again the auxiliary (*heft/hebben*) would disambiguate the role of this pronoun in relative clauses. These conditions were also contrasted with embedded marked pronouns that were not ambiguous (*ons/wij*).

32. (a) **Ambiguous-NP / SR**
    Ongerust kijkt de hardloper, die de wandelaars in het park gegroet heeft, naar de regenwolken in de lucht.
    (Worried looks the jogger, who strollers in the park greeted has, at the rain clouds in the sky.)
    The jogger, who has greeted the strollers in the park, looks worried at the rain clouds in the sky.

    (b) **Ambiguous-NP / OR**
    Ongerust kijkt de hardloper, die de wandelaars in het park gegroet hebben, naar de regenwolken in de lucht.
    (Worried looks the jogger, who the strollers in the park greeted has, at the rain clouds in the sky.)

The jogger, whom the strollers have greeted in the park, looks worried at the rain clouds in the sky.

(c) **Ambiguous-Pro / SR**
Ongerust kijkt de hardloper, die jullie in het park gegroet heeft, naar de regenwolken in de lucht.
(Worried looks the jogger, who you-PL in the park greeted has, at the rain clouds in the sky.)
The jogger, who has greeted you in the park, looks worried at the rain clouds in the sky.

(d) **Ambiguous-Pro / OR**
Ongerust kijkt de hardloper, die jullie in het park gegroet hebben, naar de regenwolken in de lucht.
(Worried looks the jogger, who you-PL in the park greeted have, at the rain clouds in the sky.)
The jogger, who has greeted us in the park, looks worried at the rain clouds in the sky.

(e) **Marked-Pro / SR**
Ongerust kijkt de hardloper, die ons in het park gegroet heeft, naar de regenwolken in de lucht.
(Worried looks the jogger, who us-ACC in the park greeted has, at the rain clouds in the sky.)
The jogger, who has greeted us in the park, looks worried at the rain clouds in the sky.

(f) **Marked-Pro / OR**
Ongerust kijkt de hardloper, die wij in het park gegroet hebben, naar de regenwolken in de lucht.
(Worried looks the jogger, who we-NOM in the park greeted have, at the rain clouds in the sky.)
The jogger, whom we greeted in the park, looks worried at the rain clouds in the sky.
(Mak et al., 2008, p. 173)

Mak et al. (2008) found that subject relatives (32a) had shorter reading times than object relatives (32b) at the two regions (*near, de*) following the auxiliary when there was a full noun phrase (*wandelaars*) in the relative clause. Interestingly, in the ambiguous personal pronoun condition, this pattern was reversed: subject relatives (32c) had longer reading times than object relatives (32d) at the two words after the disambiguating auxiliary. Mak et al. (2008) argued that this effect is explained by the topichood hypothesis, the referent of the personal pronoun should be as topic-worthy to be the subject of the relative clause as the relative pronoun. Readers prefer to assign the subject role in the relative clause to the referent of the personal pronoun. Thus, the type of embedded noun phrase had a main effect on the comprehension difficulty of relative clauses.

However, the personal pronouns in the marked conditions (32e, 32f) in the first experiment might have provided an explicit cue about the role of the pronoun. Thus, Mak et al. (2008) argued that such a cue is necessary for the topichood to affect sentence processing. Therefore, Mak et al. (2008) tested whether topichood factors from outside the sentence (such as context) might influence sentence processing. In a second self-paced reading experiment, Mak et al. (2008) gave participants some context information which either entailed the topic of the critical sentence or the context was neutral concerning the context of the critical sentence. In the critical sentence, the auxiliary *heeft/hebben* disambiguated the role of the relative pronoun *die* to be either the subject (33a) or the object of the relative clause (33b).

33. **neutral context**

Onlangs is er ingebroken in een grote villa in deze wijk. De inbraak heeft veel opschudding veroorzaakt. Ook heeft de zaak veel aandacht gekregen in de media.

Recently there has been a burglary in a villa in this area. The burglary has caused a lot of excitement. The media have devoted much attention to the case.

topic context

De inbreker was opgepakt bij een inbraak in een grote villa. Hij wilde enkele dure juwelen stelen uit het pand. Ook wilde hij geld meenemen.

The burglar has been arrested during a burglary in a large villa. He wanted to steal some expensive jewelry from the house. He also wanted to take some money.

(a) **subject relative** De politie heeft de bewoners, die de inbrekers hebben neergeslagen, verteld dat de man nog meer misladen heeft gepleegd.
(The police have the occupants, that the burglar have knocked down, told that the man has committed more crimes.)
The police have told the occupants, who have knocked down the burglar, that the man has committed more crimes.

(b) **object relative** De politie heeft de bewoners, die de inbrekers heeft neergeslagen, verteld dat de man nog meer misladen heeft gepleegd.
(The police have the occupants, that the burglar has knocked down, told that the man has committed more crimes.)
The police have told the occupants, whom the burglar has knocked down, that the man has committed more crimes.

concluding sentence

De politie is blij dat de inbreker is opgepakt.

The police are glad that the burglar has been arrested.

(Mak et al., 2008, p. 178)

Mak et al. (2008) reported that subject relatives (33a) had better comprehension scores than object relatives (33b) when the critical sentence was preceded by a neutral context. Object relatives had longer reading times at the verb (*hebben / heeft*) than subject relatives. However, when the critical sentence was preceded by a context containing the topic then there was no difference between object and subject relatives at the verb. This difference was observed later at the region after the past participle. This indicated that external topichood factors affect the comprehension of the sentence and topichood does not necessarily need to be signalled by the form of the relative clause noun phrase. Therefore, Mak et al. have shown that context topichood can affect sentence processing and in addition, effects of topichood occur early and almost instantaneously.

1.5 The time-course of comprehension processes

1.5.1 A distinction between lexical and structural processes

Tily, Fedorenko, and Gibson (2010) investigated effects of lexical and structural information during sentence processing. Models like constraint-based approaches (MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell et al., 1994) claimed that lexical information is accessed in parallel to the structural information. Tily et al., on the other hand, presented findings indicating that lexical access precedes structural processing.

In an online self-paced reading experiment, Tily et al. (2010) contrasted subject-extracted (34a, 34c) with object-extracted cleft sentences (34b, 34d). Object-extracted and subject-extracted cleft structures are similar to object-relative and subject-relative clauses: object-extracted clefts are harder to understand than subject-extracted cleft sentences (Gibson, 1998). In addition to the sentence structure, Tily et al. manipulated the frequency of the verb in the extracted cleft and contrasted high frequency verbs (*lectured*) in (34a, 34b) with low frequency verbs (*chided*) in (34c, 34d).

The object-extracted cleft conditions (34b, 34d) are predicted to be more difficult than the subject-extracted cleft conditions. In addition, the conditions with the low frequency verb (34c, 34d) should have longer reading times than the conditions with the high frequency verb (34a, 34b). According to constraint-based models, the two effects of cleft type and verb frequency should be observed together around the verb (*lectured / chided*). Tily et al. (2010), on the other hand, argued for an ordered structural and lexical processing and therefore predicted that the lexical effect should appear at the verb and the syntactic effect should be observed at one of the regions after the verb (*for always*, *being late*).

34. (a) **high frequency/subject-extracted:**
    It was | Vivian who | lectured Terrence | for always | being late.

    (b) **high frequency/object extracted:**
    It was | Vivian who | Terrence lectured | for always | being late.

    (c) **low frequency/subject extracted:**
    It was | Vivian who | chided Terrence | for always | being late.

    (d) **low frequency/object extracted:**
    It was | Vivian who | Terrence chided | for always | being late.
    (Tily et al., 2010, p. 913-914)

At the critical region (*lectured Terrence / Terrence lectured*) Tily et al. (2010) reported a main effect of the lexical manipulation: conditions with the high-frequency verb (*lectured*) in (34a, 34b) were read faster than conditions with the low-frequency verb (*chided*) in (34b, 34c). This effect was modulated by an interaction at the critical region: in the high-frequency verb condition object-clefts had longer reading times than subject-clefts. The difference between the object- and subject-clefts was not significant in the low-frequency verb condition.

The analysis of the reading times on the post cleft region (*for always*) showed a lexical and a structural main effect. High frequency conditions (34a, 34b) were read faster than low frequency conditions (34c, 34d) and the object-extracted clefts (34b, 34d) were read slower than the subject-extracted clefts (34a, 34c) at *for always*. There was no interaction at the post-cleft region.

According to Tily et al. (2010), the reported main effect and the interaction at the cleft region is in agreement with the account of early lexical access. The frequency effect was observed early at the point in the sentence when the verb needs to be accessed. In addition, the interaction at the cleft-region showed that structural effects can occur early when a high-frequency verb can be easily accessed. When the verb is harder to access, e.g. due to its low frequency, the structural effect was delayed to the post cleft region. Tily et al. argued that the time-course of the two effects showed that some structural operations only start after the lexical information of the verb has become available. This observation showed how lexical information can affect syntactic processes. This observation is incompatible with the predictions made by syntax-first models (?, ?), which claimed that syntactic processing is largely unaffected by lexical information of the items encountered during parsing.

However, there is a possible confound in the sentence materials: the embedded verb in subject relative clauses appeared earlier than the embedded verb in object relative clauses. Therefore, the low frequency of *chided* might have had more of an effect at the critical region on the subject-relative condition (30c) than on the object-relative condition (30d). Thus, this frequency effect and the relative clause effect might have overridden each other at the critical region.

1.5.2 A staged architecture for lexical and structural processing

While Tily et al. (2010) showed that lexical access can delay structural integration in object-cleft sentences, Staub (2011) presented findings for garden-path structures that suggest that not only does lexical access precede a structural reanalysis effects, lexical access also does not affect the size of the reanalysis effect.

Staub (2011) used eye-tracking to investigate the time-course of the processing of garden-path sentences when the disambiguating verb is either low or high in frequency. Example (35) contrasted locally ambiguous sentences (35c, 35d) with unambiguous sentences (35a, 35b). Initially *the students* for the conditions (35c) and (35d) could either be interpreted as the object of the main sentence or the subject of a reduced complement clause. This ambiguity will be resolved when readers encounter the verb *walked / ambled*. Thus, the appearance of the verb *walked/ambled* should induce a garden-path effect. In addition to the garden-path effect, the critical verb was also either a high frequency verb (35a, 35c) or a low frequency verb (35b, 35d). Thus, there are two effects associated with the embedded verb *walked / ambled*. Considering the results reported by Tily et al. (2010), the lexical manipulation should affect the structural processing in two ways (1.) lexical frequency should affect the size of the garden-path effect and (2.) it should delay the garden-path effect.

35. (a) **unambiguous / high frequency**
    The professor saw that the students| walked| across| the quad.
    (b) **unambiguous / low frequency**
    The professor saw that the students| ambled| across| the quad.
    (c) **ambiguous / high frequency**
    The professor saw the students| walked| across| the quad.
    (d) **ambiguous / low frequency**
    The professor saw the students| ambled| across| the quad.
    (Staub, 2011, p. 8)

Staub (2011) reported an effect of word frequency at the critical verb (*walked / ambled*) for the reading times, but not the regression rate. High frequency verbs (35a, 35c) were read faster than low frequency verbs (35b, 35d). Ambiguity affected regressions and the go-past times on the spillover region (*across*). Ambiguous conditions (35c, 35d) induced more regressive eye movements and longer go-past times from the spillover area than the unambiguous conditions (35a, 35b).

This finding seems to suggest that effects of verb frequency and ambiguity resolution are sequenced. The reading times at the critical verb (*walked / ambled*) showed an effect of frequency in the reading times, but no effect of ambiguity. A garden-path effect was only observed at the spill-over region (*across*) after the verb and only in late measures such as go-past reading time and regressions. According to Staub (2011), when one word triggers a frequency as well as a garden-path effect, the frequency effect precedes the garden-path effect. Since there was no interaction reported, Staub argued that the size of the garden-path effect is unaffected by the verb frequency.

These findings are not in agreement with the results reported by Tily et al. (2010) who claimed that the lexical manipulation affected the size of the structural effect. One crucial difference is that Tily et al. used sentence clefts and Staub (2011) used reduced complement clauses to investigate structural effects. The difference might be due to the different sentence structures. In addition, while Tily et al. used self-paced reading, Staub investigated the time-course of lexical and structural processing with eye-tracking, which provides several measures reflecting early and late cognitive processes. The difference of the observed effects between the Tily et al. and the Staub might be a consequence of the different paradigms used.

1.5.3 Time course of anaphor resolution

Tily et al. (2010) and Staub (2011) presented findings about the time course of verb frequency effects in sentence processing. Staub found that while verb frequency affects reading times it does not affect reanalysis processes. Tily et al. reported an early effect of verb frequency, which then affected structural processing. In addition, Sturt (2003) investigated the time course of different processes during anaphor resolution using eye tracking. Anaphor resolution describes the resolution of references during sentence processing. Consider the example (36). According to linguistic constraints in binding theory, the reflexive *himself* in example (36a) refers to *Peter* because *John* cannot be the referent of *himself*. In (36b), on the other hand, *him* refers to *John* as that referent that *Peter hates*.

36. (a) **reflexive**
    John thinks that Peter hates himself.

    (b) **pronoun**
    John thinks that Peter hates him.

(Sturt, 2003, p. 542)

According to the binding-as-initial filter principle, binding constraints are used at the earliest stage, therefore *Peter* in (36a) is immediately identified as the antecedent for *himself*. By choosing *Peter*, *John* is quickly ruled out as a referent for *himself*.

Sturt (2003) investigated anaphor resolution using sentences like (37). Example (37) contained an introductory sentence with either a male or a female name (*Jonathan / Jennifer*), a sentence starting with a pronoun that refers back to that name (*He / She*), this is followed by a stereotypical gender noun (*surgeon*) and then a reflexive pronoun (*himself / herself*). According to binding theories, *himself* refers to *the surgeon*. *The surgeon* is the accessible antecedent of *himself*. Choosing *the surgeon* as the antecedent of *himself*, the subject *he* is ruled out to be the antecedent and is therefore the inaccessible antecedent. In addition to the accessibility of antecedents, the gender match between the reflexive (*himself / herself*) and both, accessible (*surgeon*) and inaccessible (*He / She*), antecedents were manipulated. For the accessible antecedent, Sturt (2003) manipulated the stereotypical gender perception: for example *the surgeon* is stereotypically perceived to be male.

The binding-as-initial filter account predicted that the gender of the inaccessible item (*He / She*) should not have an effect on the anaphor resolution. The accessible antecedent *the surgeon* will be quickly identified for *himself*. Binding principles apply quickly and cannot be corrected at a later time. This contrasted with the binding-as-a-defeasible filter. Here, the antecedent of the reflexive is also quickly identified but with the difference that these binding interpretations can be subject for violations at a later time. According to binding-as-defeasible filter, the gender of the inaccessible item (*He / She*) can have an effect on comprehension.

Sturt (2003) used eye tracking to investigate the time-course of binding during sentence comprehension.

37. (a) **accessible-match / inaccessible-match**
    Jonathan was pretty worried at the City Hospital. He remembered

that | the surgeon had pricked | himself | with a| used syringe | needle. There should be an investigation soon.

(b) **accessible-match / inaccessible-mismatch**
Jennifer was pretty worried at the City Hospital. She remembered that | the surgeon had pricked | himself | with a | used syringe | needle. There should be an investigation soon.

(c) **accessible-mismatch / inaccessible-match**
Jennifer was pretty worried at the City Hospital. She remembered that | the surgeon had pricked | herself | with a | used syringe | needle. There should be an investigation soon.

(d) **accessible-mismatch / inaccessible-mismatch**
Jonathan was pretty worried at the City Hospital. He remembered that | the surgeon had pricked | herself | with a | used syringe | needle. There should be an investigation soon.
(Sturt, 2003, p. 546)

The early measures the first fixation duration and the first-pass time showed the expected effect of anaphor and antecedent gender mismatch on the reflexive pronoun (*himself / herself*). The reading times were faster for sentences (37a) and (37b) when the gender of the anaphor matched the stereotypical gender of the accessible noun.

Interestingly, there was an effect in the later reading time measures. When the accessible antecedent matched the anaphor, second pass reading was longer at the pre-final region (*used syringe*) when the anaphor (e.g. *himself*) and the inaccessible antecedent (e.g., *She*) mismatched (36b) than when the anaphor and the inaccessible item matched (37a).

These findings are not consistent with the binding-as-initial filter account. The early effects suggested that binding principles were applied quickly, but the late effects in the reading times indicated that these initial binding interpretations were subject to violations at a later time. This finding is consistent with the binding-as-defeasible filter account.

Sturt (2003) assumed that the effect on the pre-final region in second-pass reading was mainly driven by regressive eye movements from the final word *needle*. Therefore, this effect might be part of final integrative sentence wrap-up processes. Thus, binding might apply late and some principles apply in order to recover from initial sentence misinterpretation as part of sentence wrap-up processes.

1.6 Similarity based interference

The previous sections have described various accounts of how working memory affects sentence comprehension. Researchers have used complex sentences, for instance relative clause structures, to investigate how and when readers will have difficulty understanding a sentence. Locality, for example, explained processing difficulty in terms of the distance between items that need to be integrated with each other. Surprisal, on the other hand, claims that difficulty is associated with the low expectation of an item. This section (1.6) introduces another account of sentence processing difficulty: similarity based interference. Similarity based interference assumes that difficulty during sentence comprehension arises because items have to be temporarily stored in memory. In memory, these items interfere with each other, decreasing the quality of their memory traces. The more similar these items in memory are the more pronounced the more pronounced interference during comprehension.

1.6.1 How can similarity based interference affect relative clauses and sentence clefts?

Similarity based interference research in sentence processing stems from general memory research that has reported that when to-be-memorised items are semantically similar it is more difficult to recall these items (Gorfein & Jacobson, 1972, 1973). Bever (1974) made a similar observation for the processing of sentences that contain two centre-embedded relative clauses. Sentences with two object-relative clauses embedded in each other like Example (38) are especially hard to understand. Bever (1974) assumed that by mixing the noun phrase types in the relative clauses, the complexity should be reduced and Sentence (38b) should be easier to understand than Sentence (38a).

38. (a) **same noun phrase type**
The reporter the politician the commentator met trusts said the president won't resign.

(b) **different noun phrase type**
The reporter everyone I met trusts said the president won't resign.
(Gordon et al., 2001, p. 1412)

According to a similarity based interference approach, the nouns *reporter*, *politician*, *commentator* in (38a) have to be integrated with their respective verbs (*met, trusts, said*) later on in the sentence. During online sentence comprehension, these items have to be temporarily stored until the verbs become available. Therefore, when a verb (e. g., *trusts*) is encountered it should be harder to identify its target subject (*politician*) when the nouns in memory have the same noun phrase type and are therefore similar to each other (*reporter*, *politician*, *commentator* in 38a). In contrast, it should be easier at the verb *trusts* in (38b) to identify its target subject *everyone* among the other different items in memory (*reporter, I*).

Gordon et al. (2001) tested the predictions made by Bever (1974) using the self-paced reading paradigm. Example (39) contrasts sentences containing a single subject- (39a, 39b) with a single object-relative clause (39c, 39d). The embedded noun phrase in these sentences was a proper noun (*the lawyer*) or an indexical pronoun (*you*). Gordon et al. argued that according to the assumptions made by Bever, conditions with different noun phrases (38b, 38d) should be easier at the verb (*climbed*). When encountering *climbed*, the parser has to choose among two potential targets (*barber, lawyer*) that are stored in memory.

According to similarity based interference, the identification of the correct noun is easier when the potential targets are different from each other (*barber, you* in 39b, 39c) than when they are similar (*barber*, *lawyer* in 39a, 39c). In addition, the similarity between the noun phrases should also affect the relative clause processing. Object relatives are expected to be harder at *climbed* because there are two nouns in memory that have a subject role (*barber* as the sentence subject and *lawyer / you* as the relative clause subject). When both of these are of the same type, this should make the object relative condition more difficult. In the subject relative condition, the two noun phrases in memory already differ: one is the sentence subject (*barber*) and the other is the relative clause object (*lawyer / you*), therefore subject relatives should be easier than object relatives at the main verb *climbed*.

39. (a) **subject relative / similar noun type**
    The barber that admired the lawyer climbed the mountain.

    (b) **subject relative / different noun type**
    The barber that admired you climbed the mountain.

    (c) **object relative / similar noun type**
    The barber that the lawyer admired climbed the mountain.

    (d) **object relative / different noun type**
    The barber that you admired climbed the mountain.
    (Gordon et al., 2001, p. 1414).

Reading times at the verb (*climbed*) were faster for the conditions with the embedded pronoun (39b, 39d) than those with the embedded proper noun (39a, 39c), though this difference might be due to the length difference between the short pronoun (*you*) and the long proper noun (*the lawyer*). There was no main effect of relative clause type at *climbed*. More interesting, there was an interaction between the type of relative clause and the type of noun phrase: object relative conditions were read slower than subject relative conditions when the embedded noun was a proper noun (*lawyer* in 39a vs. 39c) but not when the embedded noun was a pronoun (39b vs. 39d). This effect was observed at the position of the embedded noun (*lawyer*).

Thus, Gordon et al. (2001) showed that the difficulty of embedded object relatives can be reduced when the two noun phrases are different. This finding is in agreement with the assumption made by Bever (1974).

The first experiment of Gordon et al. (2001) showed that since the pronoun and the proper noun are less similar than two proper nouns, the difficulty of the object relative condition could be reduced. However, the use of relative clauses constrained the experimental conditions in Gordon et al.

(2001): in relative clauses, it is not possible to have a pronoun as a sentence subject like in (40).

40. * You that admired the barber climbed the mountain.

Because of that restriction, the experimental manipulation of the noun phrase types could not be fully counter-balanced in (39). If similarity based interference applied during sentence comprehension, there should be less interference when the first noun phrase is a pronoun and the embedded noun phrase is a description (or proper noun). Due to the nature of relative clauses, this could not be tested in the first experiment. Therefore Gordon et al. (2001) conducted another self-paced reading experiment comparing different kinds of noun phrases using sentence clefts (41). Clefts, like relative clauses, can take an object- and subject-extracted form, but in contrast to relative clauses their first noun can be a name or a pronoun. (This is because clefts do not require unique referent identification of the first noun phrase.) In another experiment, Gordon et al. (2001) presented names (*John, Bill*) and descriptions (*the barber, the lawyer*) at the subject and the sentence cleft region in (41). According to an interference account, conditions with different types of noun phrases should reduce the object relative difficulty. That effect should occur irrespective of the position of a specific noun phrase type in the sentence.

41. (a) **subject cleft / same**
    - i. **description / description**
      It was the barber that saw the lawyer in the parking lot.
    - ii. **name / name**
      It was John that saw Bill in the parking lot.

    (b) **subject cleft / different**
    - i. **description / name**
      It was the barber that saw Bill in the parking lot.
    - ii. **name / description**
      It was John that saw the lawyer in the parking lot.

(c) **object cleft / same**

    i. **description / description**
    It was the barber that the lawyer saw in the parking lot.

    ii. **name / name**
    It was John that Bill saw in the parking lot.

(d) **object cleft / different**

    i. **description / name**
    It was the barber that Bill saw in the parking lot.

    ii. **name / description**
    It was John that the lawyer saw in the parking lot.
    (Gordon et al., 2001, p. 1418).

The critical region in this experiment was the last word of the sentence cleft (*lawyer, Bill* in the subject- and object-extracted condition). Gordon et al. (2001) reported a main effect of noun phrase similarity: the similar conditions (41a, 41c) were read slower than the dissimilar conditions (41b, 41d).

More importantly, the critical finding was an interaction between similarity and the sentence cleft type. Object clefts were significantly harder than subject clefts when the noun phrases were similar. The difference between object and subject clefts was not significant when the noun phrases were similar.

As a summary, the two experiments of Gordon et al. (2001) presented here supported the original assumption made by Bever (1974). By presenting different types of noun phrases in a relative clause setting, the difficulty of object relative clauses could indeed be reduced. While the presentation of different types of noun phrases could not be fully counterbalanced in the first experiment due to the nature of the relative clauses, Gordon et al. used sentence clefts in the second experiment and showed that object relatives are easier when the types of noun phrases mismatched in a fully counter-balanced design. Thus, these findings support a similarity based interference account.

1.6.2 Does sentence processing make use of memory resources?

Gordon, Hendrick, and Levine (2002) investigated whether interference is due to general or specific working memory processes. Gordon et al. presented findings of a self-paced reading experiment that combined a memory and a reading comprehension task. The experiment contained sentences that contrasted object- (42ii,42iv) and subject-extracted (42i, 42iii) clefts with the two noun phrases both being either names or descriptions. In addition to the sentence processing task, a list of three words was presented before the sentence appeared on the screen, which had to be memorised. These three words either matched the noun phrase type used in the sentence (42a) or they did not match (42b). Gordon et al. argued that the memory task should compete with the sentence processing task and thus draw from the same memory resources. The word list with the matching noun phrase type (42a) should interfere with the memory processes involved during sentence comprehension. Thus, Gordon et al. predicted that the matched conditions (42a) should be harder to read than the unmatched conditions (42b) and this effect should interact with the type of the sentence cleft: the subject-object relative should be larger in the matched than in the unmatched condition.

42. (a) **Matched**

    i. **Name load / subject cleft**
    memory list: Joel-Greg-Andy
    It was Tony that liked Joey before the argument began.

    ii. **Name load / object cleft**
    memory list: Joel-Greg-Andy
    It was Tony that Joey liked before the argument began.

    iii. **Description load / subject cleft**
    memory list: poet-cartoonist-voter
    It was the dancer that liked the fireman before the argument began.

    iv. **Description load / object cleft**
    memory list: poet-cartoonist-voter

It was the <u>dancer</u> that the <u>fireman</u> liked before the argument began.

(b) **Unmatched**

i. **Name load / subject cleft**
memory list: poet-cartoonist-voter
It was <u>Tony</u> that liked <u>Joey</u> before the argument began.

ii. **Name load / object cleft**
memory list: poet-cartoonist-voter
It was <u>Tony</u> that <u>Joey</u> liked before the argument began.

iii. **Description load / subject cleft**
memory list: Joel-Greg-Andy
It was the <u>dancer</u> that liked the <u>fireman</u> before the argument began.

iv. **Description load / object cleft**
memory list: Joel-Greg-Andy
It was the <u>dancer</u> that the <u>fireman</u> liked before the argument began.
(Gordon et al., 2002, p. 427)

Gordon et al. (2002) reported an interaction between sentence cleft type and the type of words recalled in the predicted direction for comprehension question accuracy: the error rate for the comprehension rates (Readers had to give true/false responses to statements such as *The fireman liked the dancer* (Gordon et al., 2002, p. 427).) was higher when the type of noun phrase that had to be recalled matched the type of noun phrase in the object-extracted sentence cleft (42aii, 42aiv) than when the type of noun phrases did not match the noun phrase type in the object-extracted condition (42bii, 42biv). The difference in error rates was not significant in the subject relative conditions between the matching (42ai, 42aiii) and mismatching noun phrases (42bi, 42biii).

Reading time results showed that the object extracted conditions took longer to read at the cleft region (*Joey liked*, *liked Joey*) and at the region after the cleft (*before the argument began*) than the subject extracted conditions.

There was also a main effect of noun phrase match in the reading times at the initial region (*It was Tony that*): matched conditions (42a) had longer reading times than the unmatched conditions (42b). However, there was no interaction in the reading time measures.

These findings have two implications: First, when the noun phrase types in a memory list match the noun phrases used in a sentence, sentence comprehension becomes harder. Second, this difficulty is even more pronounced for syntactically complex structures.

Gordon et al. (2002) argued that the interaction of an external memory load (memorising a list of words) with sentence comprehension is at odds with the idea of a separate specialised resource for sentence processing which was argued for by Caplan and Waters (1999). Thus, Gordon et al. concluded that processes involved in memorising a list of words and those involved in the comprehension and structuring of a sentence use the same memory resources.

1.6.3 Testing the characteristics of an embedded noun phrase type

Gordon, Hendrick, and Johnson (2004) furthermore tested interference effects that arise due to the similarity of different aspects of the noun phrases that have to be stored in memory. The embedded noun phrase was either a definite (*the accountant*) or an indefinite noun phrase (*an accountant*) in Experiment 1 of Gordon et al. (2004). In Experiment 2, Gordon et al. (2004) contrasted embedded singular noun phrases (*the accountant*) with embedded plural noun phrases (*accountants*). Finally, in Experiment 3 the definite subject (*person*) and the embedded noun phrases (*accountant*) were contrasted with their super-ordinate description (*person*). The different noun phrase types were contrasted in object- and subject-relative sentences for the three first experiments. Gordon et al. (2004) found an effect of relative clause type for all three experiments, but no effects of the noun phrase manipulation and more important no interaction between relative clause type and noun phrase similarity. Thus, there was no significant difference for the contrast of definite versus indefinite noun phrase, singular versus plural noun phrase and definite noun versus super-ordinate description in a relative clause setting. The first three experiments in Gordon et al. (2004) showed that noun phrases that were manipulated for their structural semantics (super-ordinates like *person* contain less semantic information than definite noun phrases like *the accountant*) or their accessibility in discourse (generics like *accountants* are, according to the givenness hierarchy, more given in a current discourse) do not affect the comprehension of complex sentences structures like relative clauses.

While the first three experiments in Gordon et al. (2004) did not show an effect of the embedded noun phrase, Warren and Gibson (2002) presented results that showed an effect of a different embedded noun phrase. In one of three acceptability rating studies Warren and Gibson used double centre-embedded relative clause sentences. Warren and Gibson reported that the complexity ratings decreased when the quantified pronoun (*everyone*) was in the centre-most position (43c).

43. (a) **doubly nested / outer position**
    Everyone who the journalist who the photographer met liked was at the party.
    (b) **doubly nested / middle position**
    The photographer who everyone who the journalist met liked was at the party.
    (c) **doubly nested / inner position**
    The journalist who the photographer who everyone met liked was at the party.
    (Warren & Gibson, 2002, p. 91)

A self-paced reading experiment in Gordon et al. (2004) tested whether the finding described in Warren and Gibson (2002) for double centre-embedded sentences could also be observed for single embedded relative clauses. Using the self-paced reading paradigm, the experiment contrasted object-relative (44a, 44b) with subject-relative (44c, 44d) clauses with either a definite noun phrase (*the accountant* in 44a, 44c) or a quantified pronoun (*everyone* in 44b, 44d) in the embedded position.

44. (a) **object-relative / same noun type**
The salesman that the accountant contacted spoke very quickly.

(b) **object-relative / different noun type**
The salesman that everyone contacted spoke very quickly.

(c) **subject-relative / same noun type**
The salesman that contacted the accountant spoke very quickly.

(d) **subject-relative / different noun type**
The salesman that contacted everyone spoke very quickly.
(Gordon et al., 2004, p. 109).

Gordon et al. (2004) reported a main effect for relative clause type: object relatives (44a, 44b) were read slower at the two critical regions (1: *the accountant/contacted*, 2: *spoke*) than subject relative clauses (44c, 44d). Furthermore, there was an interaction effect between relative clause type and noun phrase type. The subject-object relative clause difference (object relatives had longer reading times than subject relatives) was more pronounced for embedded definite noun phrases (*accountant*) than for quantified pronouns (*everyone*).

Previous research by Gordon et al. (2001) showed that the difficulty associated with the understanding of an object relative clause was reduced when the second noun phrase was a pronoun or a name. Gordon et al. (2004) investigated *structural semantic* (definite and generic) and *lexical semantic* (rich descriptions and lean superordinates) characteristics of noun phrases at the embedded position. Neither manipulations reduced the subject-object relative clause difference when they were contrasted with a definite noun phrase. The argument from Gibson (1998) and Warren and Gibson (2002) that those noun phrases that have a higher activation in discourse (names and pronouns) reduce sentence complexity was not supported by the findings in this experiment in Gordon et al. (2004).

So what are the features that cause two noun phrases to interfere during sentence processing? Gordon et al. (2004) argued that it is the semantic content of the two noun phrases that causes interference. Pronouns, names and quantifiers are not directly semantically defined, that is why they can be more directly referred to than definite noun phrases. Thus, according to Gordon et al., because proper noun phrases are more semantically specified they are harder to process when they are embedded in a relative clause.

In addition, Gordon et al. (2001) reported an interaction effect for cleft structures that showed that dissimilar noun phrase types reduce the subject-object difference. This finding indicates that noun phrases stored in memory interfere with each other and that interference might be an effect that is not limited to information retrieval.

1.6.4 Time course of similarity based interference

In an earlier study discussed above, Gordon et al. (2001) showed in a self-paced reading experiment that embedding a name in a relative clause when the subject is a proper noun can reduce the difficulty of object relative clauses. Gordon et al. (2006) described three eye-tracking experiments investigating how and when the similarity between noun phrases draws on memory processes that affect the comprehension of complex sentences.

In the first eye-tracking experiment, Gordon et al. (2006) presented sentences that either contained object-relatives (45c, 45d) or subject relative clauses (45a, 45b) with an embedded description(*barber* in 45a, 45c) or an embedded name (*Sophie* in 45b, 45d). Using eye-tracking, Gordon et al. investigated the time-course of interference: how does the match of noun phrase type (when both noun phrases are descriptions vs both noun phrases are names) affect their integration with the verb *praised*? Gordon et al. predicted that by presenting a different noun phrase type (different from the subject noun type) in the embedded position, the difficulty that is associated with object relatives should be reduced. Thus, condition (45c) should be harder than (45d). In addition, similarity based interference predicts that this effect should be observed at the verb when the two noun phrases need to be retrieved from memory in order to be integrated with the verb *praised*.

45. (a) **subject-relative / description**
The banker that praised the <u>barber</u> climbed the mountain just

outside of town.

(b) **subject-relative / name**
The banker that praised Sophie climbed the mountain just outside of town.

(c) **object-relative / description**
The banker that the barber praised climbed the mountain just outside of town.

(d) **object-relative / name**
The banker that Sophie praised climbed the mountain just outside of town.
(Gordon et al., 2006, p. 1306).

Early reading time and late reading time measures showed an interaction at the relative clause region (*praised the barber*): object relatives with an embedded description (*the barber*) in (45c) had longer reading times than object relatives with an embedded name in (45d). In comparison, the difference between embedded names and embedded descriptions in the subject relative conditions was not significant.

Gordon et al. (2006) argued that the findings in right-bounded reading and regression-path duration supported a similarity-based interference approach: similarity interference effects were observed near the verb *praised* during the retrieval of the noun phrases (*banker, barber*). The reported interaction effect for the late measure of re-reading might be an indication that similarity based interference effects extend beyond the location when information needs to be retrieved for verb integration.

Similarity based interference explains the observed effect by claiming that the the two initial noun phrases (*banker* and *barber*) in the object relatives were temporarily stored in memory before the verb (*praised*) was encountered. While they are unintegrated and stored, these two noun phrases interfere with each other and when they need to be retrieved from memory, this interference affects their retrieval, resulting in longer reading times at the verb.

Gordon et al. (2006) discussed an alternative explanation of the observed effect. It might be that the interference effect was not caused by the similarity between the noun phrases but by their linear distance. While the noun phrases are separated by only one word (*that*) in the object-extracted conditions, they are separated by two words (*that praised*) in the subject-extracted condition. Gordon et al. argued that the linear proximity of the noun phrases in memory might be a factor playing into similarity based interference.

In order to test this, Gordon et al. (2006) used double object constructions (46) in another experiment where verbs separate both noun phrases (*Mark, Brad*) and the first noun phrase (*Mark*) can be integrated with the verb before the second is faced (*Brad*). However, there is a crucial difference between these two experiments: Experiment 1 contrasted single object- with subject relative clauses in (45). One characteristic of object relatives is that two noun phrases are encountered before the verb. Thus, these two noun phrases have to be held in memory until the verb assigns their roles and integrates them. Gordon et al. (2006) argued that the verb (*climbed*) in the object relative structures of Experiment 1, triggers a memory retrieval to integrate the two noun phrases (*the banker, the barber*). This memory retrieval process is a result of the object relative structure. The structure used in Experiment 2 does not require such a retrieval since the two noun phrases are separated by the verb (*gave to* in (46)).

Nevertheless, Gordon et al. (2006) predicted more difficulty when noun phrases are similar than when they are dissimilar. Therefore, object relatives with names in the subject position (46a, 46c) should be easier than object relatives with descriptions in the subject position (46b, 46d).

46. (a) **name / name**
    After the meeting the notebook that <u>Mark</u> gave (to) <u>Brad</u> was in the hallway.

    (b) **definite noun / description**
    After the meeting the notebook that the <u>banker</u> gave (to) the <u>manager</u> was in the hallway.

    (c) **name / description**

After the meeting the notebook that <u>Mark</u> gave (to) the <u>manager</u> was in the hallway.

(d) **definite noun / name**
After the meeting the notebook that the <u>banker</u> gave (to) <u>Brad</u> was in the hallway.
(Gordon et al., 2006, p. 1320)

Gordon et al. (2006) reported a main effect of noun phrase type for all reading time measures. Names (*Mark*, *Brad*) were read faster than descriptions (*banker*, *manager*). More importantly, there was no difference between the conditions with the same noun phrase type and the different noun phrase type. Thus, the absence of a similarity based interference effect is in contrast to the findings of the previous experiment (45).

Experiment 2 in Gordon et al. (2006) did not support the finding of Experiment 1. The absence of a similarity-based interference effect in Experiment 2 suggested that it is not the proximity between noun phrases that causes interference. In the double object sentences of (46), the noun phrases (*Mark, Brad*) didn't need to be temporarily stored before the verb can be integrated because the verb separates *Mark* from *Brad*. Therefore, there is only one noun phrase in memory and this noun phrase will be integrated with the verb before the second noun phrase. The fact that there is only one noun phrase stored in memory explains why there is less of an interference effect during the processing of the sentences in (46). In addition, this result supports the assumption that the mere presence of similar noun phrases that don't have to be temporarily stored does not cause similarity based interference effects.

1.7 Retrieval interference

1.7.1 A model of storage interference

Gordon et al. (2006) claimed that similarity based interference arises for complex sentence structures when the noun phrases that have to be stored are of a similar type. That is the processing of the embedded verb in an object relative clause should be more difficult when the dependent noun phrases in memory are both descriptions in contrast to when one of the noun phrases is a name and the other a description. Lewis (1996) and Lewis (2000) introduced a different approach to the similarity based interference concept. Lewis' account incorporates concepts of traditional memory research with language processing. Gordon argued that it is the similarity of noun phrase types in memory that cause the similarity based interference effect. Lewis on the other hand described how the short-term memory of NL-Soar (NL-Soar is a computational architecture to model parsing processes) can be used to store incomplete, intermediate results (chunks) during incremental parsing.

Lewis (1996) described how phrases may be indexed under the same relation. Consider Example (47): to index sentences with an object-relative clause in NL-Soar it will be necessary to store two items (*the cat*, *the bird*) under one relation in the dependents set.

47. (a) **object-relative**
    The cat that the bird found jumped.

    (b) **subject-relative**
    The cat that found the bird jumped.
    (Lewis, 1996, p. 8)

The *cat* and the *bird* in (47a) are both indexed or stored under one structural relation (as shown in Table 3). Once a node is assigned to a structural position (Lewis (1996)), it will be removed from the dependents set. For subject relatives, there is only one noun phrase in the dependents set, while there are two for object relatives. As a result, the two noun phrases interfere for object relatives.

Table 3: Indexing two nodes from (47a)

DEPENDENTS	[$_{NP}$ the cat], [$_{NP}$ the bird]

(Lewis, 1996, p. 8)

By indexing more than just one node under one relation, Lewis (1996) can model interference effects in NL-Soar because items or nodes interfere with each other when they are stored under the same relation. Lewis argued that maximally two nodes can be indexed under one relation before memory interference effects occur. Thus, Lewis can account for the difference between object and subject relatives. The memory architecture needs to store two items (*the cat, the bird*) under one relation for an object relative clause (47a). In contrast, only one item (*the cat*) needs to be stored under spec-IP in the subject-relative condition and therefore (47a) should be harder than condition (47b) due to memory interference.

As two noun phrases need to be stored regularly in relative and complement clauses, two nodes can be processed. Lewis (1996) claimed that storing more than two nodes under one relation exceeds the limit and will make comprehension very difficult. A well-known example are double centre-embedded sentences which are known to be unacceptable (unacceptable sentences are sentences that, even though they are grammatically correct, are very hard if not impossible to understand. In (48) they are marked with a # (Gibson & Thomas, 1999; Vasishth, Suckow, Lewis, & Kern, 2010)).

48. **unacceptable double object-relative**
    # The boy that the man that the woman hired hated cried.
    (Lewis, 1996, p. 8)

In order to process Sentence (48) in NL-Soar, the memory set has to store three dependents (*the boy, the man, the woman*) under one relation. Lewis (1996) argued that Sentence (48) is very hard to understand because the number of nodes stored under one relation exceeds the number two (see Table 4). Thus, Lewis (1996) explained the difficulty of processing double centre-embedded sentences in terms of a memory interference account.

Even though using NL-Soar to model memory processes explained some of the memory effects during sentence processing, it remains an open question what exactly happens during memory interference and at what time the memory interference effect becomes available. Lewis (1996) argued that memory

Table 4: Indexing three nodes

DEPENDENTS	spec-IP:	$[_{NP}$ the boy],$[_{NP}$ the man],$[_{NP}$ the woman]

interference effects should be observable at the point when the items in memory (in (48) *the boy, the man, the woman*) need to be accessed. According to Lewis (1996) when noun phrases in memory compete with each other, one or several noun phrases will be dropped from the head/dependents set seen in Table 4. According to the recency preference, items that were stored more recently are less likely to be dropped from the set. Thus, for Example (48) *the boy* will be more likely to be dropped from the set of dependents than the more recent *the woman*.

1.7.2 Retrieval cue-based parsing

Two separate accounts of memory interference have been introduced so far. First, the research by Gordon suggests that memory interference effects occur in complex sentences when the noun phrases in memory are of the same type (Gordon et al., 2001, 2002, 2004, 2006). Second, Lewis (1996) introduced a model that described how a memory interference effect arises when two or more items are stored under the same relation.

Van Dyke and Lewis (2003) presented another model that explained effects of memory interference which focuses on memory retrieval processes. While other approaches argued that it is either the number of items in memory (Lewis, 1996) or the similarity between noun phrase types (Gordon et al., 2006), Van Dyke and Lewis (2003) described similarity based interference in terms of how difficult it is to retrieve an item from memory. Their retrieval approach is similar to the approaches used in episodic memory research (Gillund & Shiffrin, 1984; Hintzman, 1984), retrieval interference (McElree, Foraker, & Dyer, 2003) and activation decay approaches (Altman & Gray, 2002). Like episodic memory approaches, the account of Van Dyke and Lewis (2003) assumes that the sentence processor uses retrieval cues that find a target among a list of distractor items.

Van Dyke and Lewis (2003) used an example presented by Ferreira and Henderson (1991) to illustrate how the processor uses retrieval cues. The original study by Ferreira and Henderson presented several comprehension experiments with different two clause garden-path sentences such as (49).

49. (a) **high interference:**
When the men hunt the birds that cheetahs eat typically scatter.

(b) **low interference:**
When the men hunt the birds with bright plumage typically scatter.
(Van Dyke & Lewis, 2003, p. 294)

The garden-path effect is caused by the structural ambiguity of the verb *hunt*. The verb *hunt* can either be interpreted intransitively (without an object) or transitively (with an object). When readers interpret it transitively they assume that *the birds* is the object. This interpretation turns out to be wrong when the reader encounters *scatter* and fail to integrate it. This failure to integrate *scatter* is expected to cause a sentence processing difficulty, during which readers will have to find the ambiguous word and from there build the correct sentence structure. In their experiment, Ferreira and Henderson (1991) contrasted garden-path structures where the ambiguous region (the region between the ambiguous item *the birds* and its disambiguating item *scatter*) either contained a relative clause (49a *that cheetahs eat*) or a prepositional phrase (49b *with bright plumage*). Sentences with an object relative in the interfering region are more complex (contain interfering noun *cheetahs* and an interfering verb *eat*) than sentences with a prepositional phrase (contain an interfering noun *plumage*, but no interfering verb), in the interfering region. Thus, Condition (49a) is syntactically more complex than Condition (49b). This manipulation of complexity can affect the difficulty that is associated with the reanalysis. Since object relatives are more difficult than prepositional phrases, an object-relative in the ambiguous region should add more to the difficulty of the reanalysis than the a prepositional phrase in the ambiguous region. However, the difference in grammaticality judgements between conditions like (49a) and (49b) was not significant, according to Ferreira and Henderson. Ferreira and Henderson concluded that syntactic complexity did not affect reanalysis processes

Van Dyke and Lewis (2003) argued that the absence of a structural effect in Ferreira and Henderson stemmed from insufficient interference caused by the materials in (49). In order to integrate the verb (*scatter*) with its dependent subject (*bird*), the verb sends out a retrieval probe that contains the retrieval cues of the target noun. Those retrieval cues will be matched in parallel against the retrieval cues of the noun phrases in memory. For the verb *scatter*, there is not only a retrieval of the subject noun, but also a verb retrieval since *scatter* is the main verb that needs to be integrated with *hunt*, the verb of the preceding subordinate clause. Thus, there are two kinds of retrieval: verb and noun retrieval. The retrieval probe of *scatter* in the high interfering condition (49a) contains the retrieval cues `V, scomp` (`V`: searching for a verb and `scomp`: has to be able to take a sentence complement) for verb retrieval. For noun retrieval, the retrieval probe contains the retrieval cues `N, sing, Nom` (`N`: noun, `sing`: has to be in singular, `Nom`: has to be nominative case). The only item that might cause an interference effect in (49a) in comparison with (49b) is the verb *eat* (see Table 5). The retrieval cues of this verb, however, do not match the cues of the retrieval probe: it cannot take a sentence complement like the target *hunt*. Therefore, Van Dyke and Lewis (2003) argued, *eat* does not cause an interference effect in (49a) that would make it harder than (49b).

Table 5: Retrieval cues for verb retrieval

+V +scomp	+V +vcomp	V scomp
hunt	**eat**	**scatter**

In their experiment Van Dyke and Lewis (2003) compared the retrieval cues of Example (49) from Ferreira and Henderson (1991) with Example (50) and used an example with a stronger retrieval cue match between the verb *was* and the interfering items in memory. According to Van Dyke and Lewis (2003), the interference effect should be more severe in Condition (50b) than in (50a) at the word *was* (underlined in 50). The retrieval probe of *was* matches items with the cues `V, scomp` for verb retrieval and `N, sing, Nom` for noun retrieval (see Table 6). The noun *student* is the target subject of *was*. There are, however, two competing nouns in memory in addition to the target item. Those are *who* and *exam* for both conditions. While *who* cannot be the subject in both conditions (relative pronoun is the subject of the embedded clause, but not the matrix sentence), the role of *exam* differs between the two conditions. In (50a) *exam* is the object in the relative clause and in accusative case. In (50b), on the other hand, *exam* is the subject of the relative clause and therefore in nominative case. The retrieval probe of *was* contains the cues for a noun `N` that is singular `sing` and in nominative case `Nom`. The noun *exam* in (50b) matches these retrieval cues and therefore the noun retrieval in (50b) is more interfering than in (50a). In addition to the nouns, there are also interfering verbs that affect the integration of *was*. There is one crucial difference in the verb retrieval between (50a) and (50b). While both have a distracting *was* (underlined in 50) that interfere with the target *forgot*, (50b) also contained the verb *knew*. The distracting *was* cannot be the target of the verb retrieval since it cannot take a sentence complement like *forgot* can. The verb *knew*, on the other hand, can take a sentence complement and therefore is expected to interfere with verb retrieval. In comparison, there is no interfering verb in (50a). Therefore, both verb retrieval and noun retrieval are more interfered with in (50b) than in (50a) and thus (50a) should be easier than (50b).

50. (a) **low interference**
    The secretary forgot the student who was waiting for the exam <u>was</u> standing in the hallway.

    (b) **high interference**
    The secretary forgot the student who knew that the exam was important <u>was</u> standing in the hallway.
    (Van Dyke & Lewis, 2003, p. 294).

Table 6: Retrieval cues for both conditions

High interference						**Low interference**					
+V +scomp			+V +scomp		+V vcomp	+V +scomp			+V +vcomp		V scomp
	+N +sing +Nom	+N +sing +Nom +empty		+N +sing +Nom			+N +sing +Nom	+N +sing +Nom +empty		+N +sing +Acc	N sing Nom
forgot	**student**	**who**	**knew**	**exam**	**was**	**forgot**	**student**	**who**	**was**	**exam**	**was**

In addition to their sentences in (50), Van Dyke and Lewis (2003) tested the sentences from Ferreira and Henderson (1991) in (49) and asked participants to judge their grammaticality. Van Dyke and Lewis reported that there was no difference between the high interfering condition (49a) and the low interfering (49b) of the sentences taken from the original Ferreira and Henderson study. This is in agreement with their (Ferreira and Henderson) findings. However, there was an effect of interference in the sentences of Van Dyke and Lewis: the high interfering condition (50b) was more difficult to judge correctly than the low interfering condition (50a). Thus, for the original materials of Ferreira and Henderson, Van Dyke and Lewis could replicate the findings. However, changing the retrieval cues of the interfering verb (*knew*) made the verb retrieval and therefore the comprehension of the high interfering sentence (50b) more difficult, as the grammaticality judgments suggests. Thus, Van Dyke and Lewis concluded that their account of retrieval cue overlap can account for syntactic complexity that affects reanalysis processes.

Van Dyke and Lewis (2003) analysed off-line grammaticality ratings for sentences like (50). However, grammaticality judgements cannot provide information about online comprehension processes. Therefore Van Dyke and Lewis (2003) conducted an online self-paced reading experiment to test sentences like (51) that were similar to their sentences (50) from the grammaticality judgement experiment. The offline experiment showed that the high interference conditions were harder to judge correctly than the low interference condition. Retrieval cue-based parsing predicts that in an online study the difficulty should show at the position of the verb (*was standing*). The encounter of *was standing* initiates two processes. First, the subject noun of the verb needs to be retrieved and second, in a reanalysis process the initially misinterpreted verb (*forgot*) needs to be retrieved and reinterpreted from a verb that takes a direct object (*forgot the student*) to a verb that takes a sentence complement (*forgot that the student was standing*). For the subject retrieval, *the student* needs to be retrieved. However, the two noun phrases (*who, exam*) that are temporarily stored interfere with the subject retrieval. In addition, the verb *knew* in (51a) can, like the target verb *forgot* take a sentence complement. Therefore, the high interference condition (51a) is expected to be more difficult to reanalyse than the low interference condition (51b). This difficulty is predicted to occur at the main verb *was standing*.

51. (a) **high interference**
    The executive // assistant forgot (that) the student / who knew that the exam was important / was standing / in the // hallway.

    (b) **low interference**
    The executive // assistant forgot (that) the student / who was waiting for the exam / was standing / in the // hallway.
    (Van Dyke & Lewis, 2003, p. 305)

A pairwise comparison at the verb (*was standing*) showed that the high interfering condition (51a) was read slower than the low interfering condition (51b). This finding confirmed the grammaticality judgement reported by Van Dyke and Lewis (2003). The difference between high and low interference conditions indicated that if a syntactically more complex region needs to be reanalysed, it can affect the reanalysis process as long as this region contains interfering material. Van Dyke and Lewis (2003) showed how interference arises due to retrieval cue over lap.

To sum up, Van Dyke and Lewis (2003) presented grammaticality judgements of complex structures that either had a high interference or a low interference load. Conditions with a high similarity based interference load were harder to judge than conditions with a low similarity based interference load. In addition, Van Dyke and Lewis (2003) described the results of a self-paced reading experiment showing that the high-interference condition had the longest reading time when the verb needed to be integrated with its dependents.

However, the materials used by Van Dyke and Lewis (2003) were not fully consistent: 10 of the 36 experimental items contained an embedded plural noun phrase. Example (52a) shows that the interfering noun phrase (*the rules*) is in plural in the high interference condition, whereas in the low interfering condition (52b) *the tour group* is in singular. In another example, however, it is the other way around, the low interference condition (52d) contained a plural noun and the high interference condition (52c) an embedded singular noun. This inconsistency affects the high interference condition as the subject retrieval is actually made easier due to the number mismatching cue (mismatching with the singular main verb phrase *is doing*) of the plural noun phrase in contrast to the number matching cue of the singular noun phrase. Thus, the high interference condition is in fact less interfering when there is a plural noun phrase in the relative clause.

52. (a) **embedded plural / high interference**
    My older sister heard (that) the secretary who thinks that the rules are effective is doing too much work.

    (b) **embedded singular / low interference**
    My older sister heard (that) the secretary who is guiding the tour group is doing too much work.

    (c) **embedded singular / high interference**
    The experienced doctor felt (that) the child who thought that the illness was bronchitis was allergic to milk.

    (d) **embedded plural/ low interference**
    The experienced doctor felt (that) the child who complained about sharp stomach pains was allergic to milk.
    (Van Dyke & Lewis, 2003, p. 313)

In addition, while both conditions used in the original Ferreira and Henderson (1991) study had the same number of words, the high interference condition was longer in the study Van Dyke and Lewis (2003). Also, the length of each of these conditions varied between the experimental items (compare 52c with 52d). Thus, the materials used by Van Dyke and Lewis might have been confounded by length and by varying interference due the retrieval cue of number of the noun phrase.

However, even though the materials used in the study of Van Dyke and Lewis (2003) were not fully controlled, retrieval cue-based parsing itself describes similarity based interference in extensive detail. This account predicts when similarity based interference effects become observable and describes what makes items in memory similar, which will eventually result in the interference effect.

1.7.3 Memory load and cue-based retrieval interference

Gordon et al. (2001) and Gordon et al. (2004) presented findings that showed that similarity based interference affects sentence comprehension. The difficulty of an object-relative in comparison with a subject-relative could be reduced when the types of noun phrases in memory differed in comparison to when the type of noun phrases in memory were similar. In addition to the noun phrases in the sentence, Gordon et al. (2002) tested an additional memory task that was designed to interfere with the sentence processing task. Before the presentation of each sentence, a list of three nouns (either names or roles) was presented to the participants. Participants had to memorise these and recall them after the presentation of a sentence. The research of Gordon et al. (2002)'s showed that matching noun phrase types between the memory set and the nouns presented in the sentence affected comprehension accuracy. Van Dyke and McElree (2006), however, argued that even though, Gordon et al. (2002) showed that different noun types in memory decrease interference effects, the mechanisms and especially the time-course of interference remained unclear. Therefore, Van Dyke and McElree suggested the use of retrieval cues as described in Van Dyke and Lewis (2003) arguing that a retrieval-cue parsing account could provide a measure of similarity between items. That would make it also possible to investigate interference during encoding and retrieval processes.

It is necessary during parsing to retrieve items from memory. The content-addressable retrieval cue parsing account describes how retrieval cues directly access the memory representation to identify the constituents in memory (Van Dyke & McElree, 2006; Van Dyke & Lewis, 2003). In a cleft-sentence in Example (53) three noun phrases (*boat, guy, who*) are stored in memory before the integration of the verb (*sailed/ fixed*). Retrieval cue parsing predicts that a retrieval probe directly matches the informational cues from the dependents *guy* and *boat* with their target head *sailed/fixed*. Van Dyke and McElree (2006) used the sentence in (53) and manipulated the memory demands. Van Dyke and McElree increased the memory load by presenting a list of words before the presentation of the cleft sentence. In (53b), all of these words can potentially be the object of the verb (*fixed*) in the following sentence. In comparison, in (53a) the main verb is *sailed* and none of *table, sink* and *truck* can semantically be the object of *sailed*.

In a self-paced experiment, Van Dyke and McElree (2006) contrasted load (53a, 53b) with no-load conditions (53c, 53d). Participants were asked to remember a short list of words (*table, sink, truck*) in the load conditions (53a, 53b) before the sentence was presented. After the presentation of the sentence, these words had to be recalled. In the no-load condition, no list was presented before the sentence. In addition, the main verb of the sentence could either plausibly take all the items in the memory list as an object (in (53b) *table, sink truck* can be object of *fixed*) or the verb can plausibly take none of the items in memory as object (in (53a) neither *table, sink* nor *truck* can be *sailed*). Van Dyke and McElree (2006) predicted that the items in memory in the load condition should be interfering with verb integration when they can be the object of the verb. Thus, condition (53b) should be harder than (53a) and this difficulty should be observed at the verb *fixed* in comparison with the verb *sailed*.

In addition, the no-load conditions (53c, 53d) should be easier than the load-conditions (53a, 53b).

53. (a) **non-interfering / load**
list to be remembered: table, sink, truck
It was the boat | that the guy | who lived | by the sea | <u>sailed</u> | in two sunny days.

(b) **interfering / load**
list to be remembered: table, sink, truck
It was the boat | that the guy | who lived | by the sea | <u>fixed</u> | in two sunny days.

(c) **non-interfering / no load**
It was the boat | that the guy | who lived | by the sea | <u>sailed</u> | in two sunny days.

(d) **interfering / no load** It was the boat | that the guy | who lived | by the sea | <u>fixed</u> | in two sunny days.
(Van Dyke & McElree, 2006, p. 160)

Van Dyke and McElree (2006) reported an interference effect at the verb region (*sailed / fixed*) for the reading times. The interfering conditions (53b, 53d) were read longer than the non-interfering conditions (53a, 53c). This effect was modulated by an interaction: for the interfering conditions, sentences with an additional memory task (53b) were read longer than those without a memory task (53d). While the difference between load and no-load conditions in the non-interfering sentences was not significant. Effects of memory load were found at the first two regions (*It was the boat / that the guy*) and on the last region of the sentence (*in two sunny days*). The load conditions (53a, 53b) had longer reading times than the no-load conditions (53c, 53d) in the first two regions (*It was the boat*, *that the guy*). This effect was reversed at the regions 5 (*sailed fixed*) and 6 (*in two sunny days*): the load conditions (53a,53b) had faster reading times than the no-load conditions (53c, 53d). In addition, the comprehension question accuracy showed main effects of memory load and interference. The condition with an additional memory task (load conditions 53a, 53b) had a lower accuracy rate than those without the memory task (no load conditions 53c, 53d) and the interfering conditions (53b, 53d) were answered less correctly than the non-interfering conditions (53a, 53d).

As predicted by Van Dyke and McElree (2006), the integration of *fixed* was more difficult when more items in memory shared retrieval cues with the target noun phrase (*the boat*). The fact that the interference effect was observed at the matrix verb is indication that cue overlap affects retrieval processes during verb integration. In addition, the four conditions in Van Dyke and McElree (2006) didn't differ until the critical matrix verb (*sailed / fixed*). Therefore, the reported interaction at the critical verb cannot be the result from encoding differences from the earlier part of the sentence, but must be effects of memory retrieval.

These findings are in agreement with the predictions of the retrieval cue account. Furthermore, the reading slow-down for the load conditions in contrast to the no-load conditions suggested that the items in memory interfered with retrieval process even though their retrieval cues matched the target item only partially.

Thus, the interaction between memory load and interference was predicted by Van Dyke and McElree (2006). Furthermore, the noun phrases in the memory list and the target object noun of the verb have the same type in all conditions. The account of Gordon et al. (2002), on the other hand, predicted that an interference effect arises for conditions that have matching noun phrase types in contrast to conditions with mismatching noun phrase types (e.g. pronoun, name, description). Since the noun phrase type was kept constant over all conditions in this experiments, the interaction effect reported in Van Dyke and McElree cannot be explained by the Gordon et al. (2002) account. Therefore, retrieval cues offer an alternative measure of similarity between items that is not restricted to the noun phrase type.

1.7.4 An implemented model of similarity based interference

Lewis and Vasishth (2005) described a model of reading time data such as Van Dyke and Lewis (2003) and Grodner and Gibson (2005) that is based on an architecture of memory retrievals: ACT-R. ACT-R is a model of cognitive processes that provides controlled memory buffers which are adapted by Lewis and Vasishth to model sentence processing effect. By incorporating retrieval cue parsing of Van Dyke and Lewis (2003) into ACT-R, Lewis and Vasishth are able to model effects of sentence processing difficulty caused by interference. In the version of ACT-R by Lewis and Vasishth, sentence comprehension is constrained by the capacity of memory buffers. In addition, retrieval cues are employed to guide the parsing of a sentence. This version of ACT-R would process a sentence in the following way: a left-corner parser (Johnson-Laird, 1983) initially expects a sentence S and therefore sets the first word to be part of a noun phrase NP to be followed by a verb phrase VP. When the first noun phrase is encountered, this can easily be integrated into the sentence structure, when the verb is encountered afterwards it can also be easily integrated into the already predicted sentence structure. Accordingly, once the items are integrated, the left-corner parser updates its expectation about the category of the next item. Lewis and Vasishth combined a left-corner parser with the retrieval-cue information of the items to be expected. Thus, for example in (54), the left-corner parser's initial prediction is a subject noun, a determiner *The* is encountered and can be easily integrated, then the prediction is set for a noun and when *lawyer* is read, it will be easily integrated. The predictions of the parser are set for an item that can fill the complement position, the relative pronoun *that* fills that position and can be integrated. The partial structure will be stored in the memory buffers, just before the embedded verb is encountered, the retrieval cues are set to expect a transitive verb, *hired* fits into that position. After *hired*, there is a trace $_i$ for the object of the relative clause. In order to integrate the object, *the lawyer* needs to be retrieved from the memory buffers. The verb *hired* provides the retrieval cues that the retrieval probe should search for among the items that are stored in memory (*lawyer, editor*). Both noun phrases *lawyer* and *editor* in memory share the retrieval cues of the retrieval probe and thus interfere with each other. Therefore, the integration of the embedded verb *hired* is expected to be difficult.

54. The lawyer that the editor hired$_i$ admired the writer.

(Lewis & Vasishth, 2005, p. 9)

Implementing ACT-R with the retrieval cue account, Lewis and Vasishth (2005) modeled the data of several reading times studies.

One simulation modelled an example of complex sentence structures: object- vs. subject relatives from the study of Grodner and Gibson (2005). Using self-paced reading, Grodner and Gibson reported that object-relatives (55b) had longer reading times than subject relatives (55a) and this difference was observed at the embedded verb of the object-relative clause *sent*.

55. (a) **subject-relative**
    The reporter who sent the photographer to the editor hoped for a story.

    (b) **object-relative**
    The reporter who the photographer sent to the editor hoped for a story.
    (Lewis & Vasishth, 2005, p. 386)

The simulation of the Lewis and Vasishth (2005) model showed longer reading times for the object-relative sentence (55b) than the subject-relative sentence (55a). Even though the model returned longer reading times at the main verb (*hoped*) and at the embedded verb (*sent*), the difficulty at the embedded verb (*sent*) was much more pronounced than the difficulty at the main verb (*hoped*) for the object relatives. Thus, the model of memory retrievals can account for the reading time data reported by Grodner and Gibson (2005).

Furthermore, Lewis and Vasishth (2005) modelled the data of the Van Dyke and Lewis (2003) reading study. The self-paced reading study from Van Dyke and Lewis showed that the verb region *was standing* was most difficult in the high interference (56c, 56f) in comparison to the low interference (56b, 56e) and the short conditions (56a, 56d).

56. (a) **ambiguous / short**
    The assistant forgot the student *was standing* in the hallway.

(b) **ambiguous / low interference**
The assistant forgot <u>the student</u> who was waiting for the exam *was standing* in the hallway.

(c) **ambiguous / high interference**
The assistant forgot <u>the student</u> who knew that the exam was important *was standing* in the hallway.

(d) **unambiguous / short**
The assistant forgot that <u>the student</u> *was standing* in the hallway.

(e) **unambiguous / low interference**
The assistant forgot that <u>the student</u> who was waiting for the exam *was standing* in the hallway.

(f) **unambiguous / high interference**
The assistant forgot that <u>the student</u> who knew that the exam was important *was standing* in the hallway.
(Lewis & Vasishth, 2005, p. 386-387)

The reading times of the model showed a similar pattern to the human data reported in Van Dyke and Lewis (2003). The ambiguous conditions (56a, 56b, 56c) had longer reading times than the unambiguous conditions (56d, 56e, 56f) in the model. While the human data did not show a difference between the ambiguous and the unambiguous conditions for the short sentences, the model returned faster reading times for the unambiguous condition (56d) than the ambiguous conditions (56a) in the short sentences. More importantly, the high interference conditions (56c, 56f) had longer reading times than the low interference conditions (56b, 56e), which is in agreement with the human data reported by Van Dyke and Lewis.

Using an implemented model of memory retrievals, Lewis and Vasishth (2005) showed that reported sentence processing effects can be accounted for by a series of memory retrievals and the resulting retrieval interference.

1.7.5 Are interference effects during encoding observable?

While previous research on cue based parsing investigated the point of retrieval interference, Hofmeister (2011) focussed on representational complexity of the noun phrases in memory. According to retrieval cue parsing, a verb finds its subject among a list of stored items in memory by matching the retrieval cues of these items with the retrieval cues of the verb. The subject should be found quickly without difficulty when its retrieval cues differ from those of the other items in memory, thus making it easily identifiable as the target. If, however, the retrieval cues between items in memory do not differ, the retrieval probe will have difficulty to identify the target, which might result in retrieval interference and therefore comprehension difficulty. Given the cue-based parsing account, Hofmeister questioned how the complexity of items in memory might affect their retrieval. On the one hand, a complex description (such as *alleged Venezuelan communist*) might be more difficult to encode in memory, but on the other hand once it is stored it is very distinctive and therefore might be easier to retrieve. In a self-paced reading experiment, Hofmeister tested whether the complexity of a filler in a filler-gap dependency affects retrieval (see Example (57)). In order to make a filler more complex, Hofmeister added adjectives (*alleged, Venezuelan*) to the filler noun (*communist*).

57. (a) **simple**
    It was **a communist** who the members of the club banned from ever entering the premises.

    (b) **medium**
    It was **an alleged communist** who the members of the club banned from ever entering the premises.

    (c) **complex**
    It was **an alleged Venezuelan communist** who the members of the club banned from ever entering the premises.
    (Hofmeister, 2011, p. 385)

Hofmeister (2011) reported an effect of filler complexity at the point of encoding (*communist*) and at the spillover region (*from*). While the encoding effect showed that the more complex descriptions had longer reading times (the simple condition (57a) had the shortest reading times, followed by the medium condition (57b) and finally, the complex condition (57c) had the longest reading time), the reading time pattern was reversed after the retrieval point. At the spillover region, Hofmeister observed that the more complex fillers (57c) had the shortest reading time, the medium condition (57b) was slower than the complex condition, but faster than the simple condition in (57a). Thus, Hofmeister (2011) showed that the representational complexity of items that need to be encoded into and retrieved from memory affect both processes. A more complex description (*an alleged Venezuelan communist*) does take longer to be processed and stored in memory (encoded). On the other hand, while encoding is more difficult, the retrieval of the more detailed description is easier and therefore faster than the retrieval of the short and less complex description. Hofmeister argued that the energy spend processing a more complex item is a tradeoff for when it comes to the retrieval of this item.

1.7.6 Early and late effects of retrieval cue-based parsing

The previous studies investigated how retrieval interference effects are caused by retrieval cue overlap (Van Dyke & Lewis, 2003). Van Dyke and McElree (2006) showed how an external memory load that was not part of the sentence processing task, affects the reading times at the main verb of the sentence. The most important finding in their experiment was that sentence comprehension was most difficult when the retrieval cues of the items in memory matched the retrieval cues of the target noun phrase which needed to be retrieved in order to integrate the verb into the sentence structure. Furthermore, Lewis and Vasishth (2005) described a model of guided memory retrievals, which can account for various sentence processing effects. Thus, Lewis and Vasishth argued that these effects can be accounted for by memory interference. Hofmeister (2011) has shown that not only the similarity between items in memory affects their retrieval, but also the complexity (more complex noun phrases are less similar to less complex noun phrases in memory) of the description that has to be encoded to be stored in memory.

In this context, Van Dyke (2007) described a study that distinguished between syntactic and semantic interference effects for sentences like (58). Van Dyke argued that there should be two different kinds of interference observed at the main verb *moaned*. The number of words between the subject (*lady*) and its verb *moaned* is the same in all four conditions (58a-d). However, the intervening region in (58c) and in (58d) contained two noun phrases that are subjects (*who*, *seat / man*), whereas the region in (58a) and in (58b) only had 1 noun in subject (*who*) and another in object position (*seat / man*). Since the retrieval probe of *moaned* searches for a subject noun, there should be more difficulty in (58c) and (58d). Van Dyke predicted a syntactical interference in (58c,58d) in comparison with (58a,58b).

In addition, to the number of subject nouns in the interfering region, Van Dyke (2007) contrasted the retrieval cue information of the animacy of the intervening noun phrase (*seat/man*). Van Dyke argued that an interfering noun that matches the animacy information of the subject should cause a semantic interference effect. While the inanimate *seat* is unable to *moan*, the animate interfering *man* can semantically take that position. Therefore, the high semantic conditions (58b, 58d) contained two animate noun phrases in the intervening region, whereas the low semantic condition (58a,58c) had one animate and one inanimate noun in the intervening region.

Both, the semantic and the syntactic interference should be observed at the verb *moaned*. Van Dyke (2007) tested this using eye-tracking.

58. (a) **low syntax / low semantic**
    The pilot remembered that the lady | who was sitting in the smelly seat | yesterday afternoon | moaned | about a refund | for the ticket.

    (b) **low syntax / high semantic**
    The pilot remembered that the lady | who was sitting near the smelly man | yesterday afternoon | moaned | about a refund | for

the ticket.

(c) **high syntax / low semantic**
The pilot remembered that the lady | who said that the seat was smelly | yesterday afternoon | moaned | about a refund | for the ticket.

(d) **high syntax / high semantic**
The pilot remembered that the lady | who said that the man was smelly | yesterday afternoon | moaned | about a refund | for the ticket.
(Van Dyke, 2007, p. 418)

Van Dyke reported a syntactic effect at the critical region (*moaned*) for first-pass and regression path time: the syntactically more complex conditions (58c, 58d) had longer reading times than the syntactically less complex conditions (58a,58b). At the final region (*for the ticket*), a main effect of the semantic manipulation was observed for the regression-path time: conditions with a semantically interfering noun (*man* in 58b,58d) had longer reading times than those with a semantically non-interfering noun (*seat* in 58a,58c). Interestingly, the semantic effect was modulated by an interaction: the high syntactic condition with a semantically interfering noun (58d) had longer reading times than the high syntactic condition with a semantically non-interfering noun (58c). The difference between the conditions with and without semantically interfering items for the low-syntactic conditions were not significant.

Thus, Van Dyke (2007) could find an effect of retrieval cue overlap for the syntactic cues as well as the semantic cues. An interesting finding concerns the time-course of these effects. Van Dyke predicted that the effect of the syntactic cue manipulation would be observed at the verb *moaned* and this effect was reported for first-pass and regression-path time at *moaned*. Van Dyke also predicted that the semantic cue effect would be observed together with the syntactic effect at the verb. However, this effect was only observed later at the final region *for the ticket* in regression path time.

It is noteworthy that already integrated items like *the man* could still affect the integration of the main verb *moaned*. Van Dyke (2007) argued that the observed interference effect can be explained by *cue-overload* of the items in memory. Items like *the man* that are grammatically excluded to be a subject of the verb are still considered at some point during processing as the subject. The retrieval probe is searching for a noun that is animate, which *the man* satisfied, only when *the man* is found to be not a subject, can the retrieval cues rule this candidate out.

Another important finding in Van Dyke (2007) was the observed early effect of the matching syntactic retrieval cues compared to the delayed effect of matching retrieval cues for animacy. The effect of matching retrieval cues for syntactic information and the effect of semantic cue-overlap (animacy) present a challenge to the original model by Van Dyke and Lewis (2003). Van Dyke and Lewis (2003) made no qualitative distinction between the different types of cues, all retrieval cues should be matched in parallel and therefore their effects observed at the same time. Given the results presented in Van Dyke (2007), this could not be supported. Van Dyke argued that the semantic relation (such as animacy) between the noun and the items in memory might take longer than the processing of the syntactic information. Alternatively, all necessary semantic information are only available at the end of the sentence and therefore, according to Van Dyke, the semantic effect might be part of sentence wrap-up processing.

Summary: The retrieval cues based parsing account of Van Dyke and Lewis (2003) describes how retrieval demands account for comprehension difficulty in sentence processing. To be more specific, if retrieval cues overlap between items that are temporarily stored in memory then reading time increases when these items need to be accessed later (Van Dyke & Lewis, 2003). Thus, memorising items that are similar along some dimension (Van Dyke and Lewis quantified this similarity in terms of retrieval cues) has been shown to affect processing at the point of *retrieval* of these items. Retrieval interference is expected to occur under two conditions (a) when the ability of a processor to access an item in memory decreases when the amount of information increases and (b) when the retrieval probe cannot uniquely identify the target stored in memory.

2 Experiment 1

The findings of Experiment 1 and Experiment 2 were presented in Suckow and van Gompel (2012).

As described previously, there is much evidence that object relative clauses such as (1a) are more difficult to understand than subject relative clauses such as (1b) (e.g., King and Just (1991)). The introduction has described studies that support the notion that the difficulty associated with object relatives stems from limitations in working memory (Gibson, 1998; Gordon et al., 2001; Lewis, 1996) and (King & Just, 1991).

1. (a) **subject-relative**
   The banker(s) that help(s) the accountant(s) counted the money several times.

   (b) **object-relative**
   The banker(s) that the accountant(s) help(s) counted the money several times.

As an example, King and Just (1991) found that the difference between subject and object relatives was more pronounced for low span readers. More recently, Lewis (1996) and Van Dyke and Lewis (2003) have proposed an account that assumes that working memory demands increase when two similar linguistic items (e.g., two noun phrases) need to be retrieved simultaneously, slowing down sentence processing. Lewis and Vasishth (2005) proposed an ACT-R account that explains how the processing of subject and object relatives is affected by the similarity of the noun phrases. Hofmeister (2011) then presented findings that indicate that the complexity of the noun phrase itself affects processes of encoding and retrieval. The difficulty of encoding a complex noun phrase is reversed at the point of retrieval such that a previously difficult and complex item will be retrieved more easily than an item that is easy to encode.

Consistent with this, Gordon et al. (2001) found that object relatives are easier to process when the embedded noun phrase in the relative clause is a name (*Joe*) and the head noun a definite noun phrase (the barber) compared to when both are definite noun phrases. However, Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) similarity based interference account claims that interference is not just due to similarity in the type of noun phrase but also due to similarity of other features. Van Dyke and Lewis described how the degree of overlap between a retrieval cue and two similar linguistic items may affect the retrieval of these items. Two items (the subject and object noun phrase) have to be retained in memory in object relatives until they can be integrated with the verb. At the point of integration at the verb, retrieval cues are used to identify the target item from memory. When the two items in memory share retrieval cues, it will become difficult to distinguish between the object and the subject target. Thus, a similarity based interference effect arises for items with retrieval cue similarity. The account of Lewis and Vasishth predicts that a similarity based interference effect should arise at the embedded verb in object relatives because two items have to be retrieved from memory instead of only one for subject relatives. This interference effect at the verb should be larger when these two items share retrieval cues.

For example, in object relatives like (1a) the subject and object noun phrase (*the accountant* and *the banker*) need to be simultaneously retrieved at the embedded verb (*helps*). In contrast, only one noun phrase (*the banker*) needs to be accessed at the verb (*helps*) in subject relatives like (1b). The similarity based interference effect that occurs with object relatives should be particularly strong when the two noun phrases that need to be retrieved are similar. Thus, because both the difficulty of object relatives in comparison with subject relatives and the difficulty of retrieving items that share retrieval cues are effects of interference at the embedded verb, they should occur at the same time. Van Dyke and Lewis (2003) claim that number information is one of the retrieval cues for identifying a target. In relative clauses, congruency in the number feature of the subject and object noun phrase should have a strong effect on interference, because the subject has to agree in number with the verb: The retrieval cues of the target item (the subject noun phrase) have to match the number cue of the search probe (the verb). If the object has the same number as the subject and therefore also matches the number feature of the verb, this should result in interference when the subject and object are integrated with the verb. Thus, according to the retrieval cue based interference account, retrieval difficulty at the verb (e.g., *helps*) in object relatives should be more pronounced when the two noun phrases in memory share the same number than when they do not. There should be no number interference effect at *helps* in subject relatives since there is only the target item *banker(s)* in memory and unlike with object relatives, the activation of that item is not interfered by another noun.

To test this account the current study investigated whether object relatives are harder to process when the two noun phrases in memory share the same number retrieval cue than when the number retrieval cues are different.

In sum, similarity-based interference models make the following three predictions:

1. object relatives should be harder to process than subject relatives;

2. object relatives should be particularly hard to process when the subject and object noun phrase have the same number;

3. because both the relative clause and number effect predicted in (1a) and (1b) are due to interference when the noun phrases are retrieved at the verb (*helps*), the effects should occur simultaneously.

For Experiment 1 an eye movement reading experiment was conducted that contrasted sentences containing an embedded object relative clause (1a) with an embedded subject relative (1b). The two initial noun phrases were either the same (either both singular or both plural) or different in number (one singular and the other plural).

2.1 Method

2.1.1 Participants

Experiment 1 had 40 participants. All participants were non-dyslexic English native speakers and members of the University of Dundee. They were naïve to the experimental hypothesis and received course credits in exchange for their participation. Participant treatment was in accordance with the ethical standards of the ethics committee from the University of Dundee.

2.1.2 Materials

Thirty-two critical sentences were created and presented in eight different conditions in the first eye-tracking experiment. Those were sentence with one embedded relative clause, thus the overall structure of the sentences for Experiment 1 were: `subject + [relative clause] + verb phrase.`

The experiment had a 2 × 2 × 2 design. The first variable was the type of relative clause within a sentence: sentences in condition (1.) had an embedded subject-relative clause (`verb + noun`) which were contrasted with sentences in condition (2.) that had an embedded object-relative clause (`noun + verb`). Another factor was the number congruency of the two noun phrases in the sentence. These were either the same (a., both plural or both singular noun phrases) or different (b., when one noun is singular the other noun is plural) in number. Finally, there was a counterbalancing variable for number congruency. This was included in order to control for length and morphological complexity of the two noun phrases e.g., for similar noun phrases with both singular ((a) i.) noun phrases, there was another condition with both plural noun phrases ((a) ii.). For number incongruent noun phrases with the first noun phrase plural and the second noun phrase singular ((b) i.), there was another condition with the first noun phrase singular and the second noun phrase plural ((b) ii.).

1. (a) **subject-relative / nr congruent**
   - i. The banker that helps the accountant counted the money several times.

ii. The bankers that help the accountants counted the money several times.

(b) **subject-relative / nr incongruent**

i. The bankers that help the accountant counted the money several times.

ii. The banker that helps the accountants counted the money several times.

2. (a) **object-relative / nr congruent**

i. The banker that the accountant helps counted the money several times.

ii. The bankers that the accountants help counted the money several times.

(b) **object-relative / nr incongruent**

i. The bankers that the accountant helps counted the money several times.

ii. The banker that the accountants help counted the money several times.

See the Appendix for a list of all the sentences used for Experiment 1.

Each critical item was followed by a comprehension question. These comprehension questions were constructed to ask for different information in the sentences. Yes and No-questions were equally distributed in each list.

Table 7 illustrates the different kinds of comprehension questions that were asked using one sample sentence. The structure of the material allowed for three different kinds of Yes- and No-comprehension questions. They were used to ensure that participants read and attempted to understand the whole sentences as thoroughly possible. One Yes and one No question asked about the main clause (question 1.), one Yes and one No question about the content of the relative clause (question 2.) and one Yes and one No about the relation between main and relative clause of the sentence (question 3.).

Table 7: Comprehension questions - Experiment 1

The banker that helps the accountant counted the money several times.

Yes-Questions	No-Questions
(a) Did the banker count the money?	(a) Did the banker spend the money?
(b) Has the accounted been helped?	(b) Did the accountant help anybody?
(c) Did the banker help anybody?	(c) Has the banker been helped?

In Experiment 1, 32 critical sentences and 65 filler sentences were presented. Each sentence was followed by a Yes/No comprehension question.

2.1.3 Design

Experiment 1 had a $2 \times 2 \times 2$ design: 1. relative clause type (subject relative clauses versus object relative clauses), 2. number congruency (the number feature of the noun phrases was either the same or different) and 3. number counterbalancing.

In a within-subjects design eight lists with all items (see Appendix I) were created. Each list contained thirty-two critical items with the eight conditions distributed over the lists, thus there were four items per condition in each list. The order of presentation of the critical items was constant between the eight lists, but the overall order was randomised. In addition to the 32 experimental items, 85 filler sentences were presented and Yes/No comprehension questions were presented after each sentence.

2.1.4 Apparatus and procedure

The experiment was carried out using Experiment Builder Program from SR Research on a PC. An Eyelink 1000 Desktop Mount recorded participants' eye movements at a 1000Hz sampling rate and a spatial resolution of better than 1/4 degree. Participants were seated ~60cm from the computer screen and while participants read the sentences binocularly, only the dominant eye was recorded. For a stable position throughout the experiment, participants put their heads on a chin and forehead rest. The stimuli were presented on a 19–inch CRT monitor with a resolution of 1024x768 pixels. The font was Times New Roman and all sentences were displayed on one single line. The experiment was controlled by the Experiment Builder software (SR research) on a separate PC and DataViewer (SR research) as well as R for statistical computing were used for data analysis.

After receiving participants' approval to use their data for analysis, they were asked to read the experiment instructions on the screen. The instructions described procedures of the experiment. Overall, they were asked to read sentences presented on the screen, after each sentence a comprehension question appeared and they were to answer that question with a "Yes" (right button) or with "No" (left button). There were informed that their eye-movements were recorded during the reading of the sentences. For the procedure of the experiment, they were asked to initially look at a cross on the left of the screen, after the cross disappeared a sentence appeared on the screen and they had to read and understand that sentence at their own speed. When they finished reading that sentence, they had to press a button on the button box. Then the comprehension question appeared and they had to answer this question with "Yes" (right button) or "No" (left button). In case they answered the question incorrectly, a feedback message "Wrong answer" appeared on the screen. They were also asked if they had any questions after reading the instruction. If not, a practice session would start.

A calibration process started after participants finished reading the instructions. The trials of the experiment were presented as follows: Each trial was preceded by a central calibration dot. When the fixation on this dot was detected accepted by the experiment the trial started. First a fixation cross was presented on the left of the screen. When participants fixated the fixation cross, the sentence appeared on the screen. Once they were done reading the sentence, they had to press a button on the button box and the comprehension question appeared. If the comprehension question was answered incorrectly negative feedback was given ("Wrong Answer") and if the comprehension question was answered correctly no feedback was given and the next item started with the presentation of the fixation cross. Comprehension questions were yes/no questions whose answer-type was equally distributed, meaning that 50% had to be answered with "Yes" and 50% with "No".

A break and therefore a recalibration was scheduled after 20 sentences. Thus, participants didn't have to read more than 20 sentences in a row without taking a short break from the experiment. In addition, the calibration process was also repeated when the Eye-link lost track of the eye (e.g., this might have been due to involuntary movements of the participant).

2.2 Results

Table 8 shows the areas of interest that were used for data analysis. The critical region consisted of the embedded relative clause, "helps the accountant / the accountant helps", each of the two spillover regions is at least 7 letters long (if the first word in the region is less than seven characters long, then the spillover region will be extended to the next word until the length condition of 7 characters is satisfied), the final wrap-up region is also at least 7 letters long. A space counted as one letter within a region.

Table 8: Areas of interest for materials in Experiment 1

1	**critical region**	**spillover 1**	**spillover 2**	**wrap-up**
The banker that	the accountant helps	counted	the money	several times.

First fixation duration, *first-pass time*, *regression-path time* and *total reading time* were the measures used for data analysis. These measures were analysed for the regions of interest as outlined in the materials section.

First fixation duration is defined as the length of the very first fixation on the specific area of interest provided that this fixation was not preceded by a fixation on an interest region to the right.

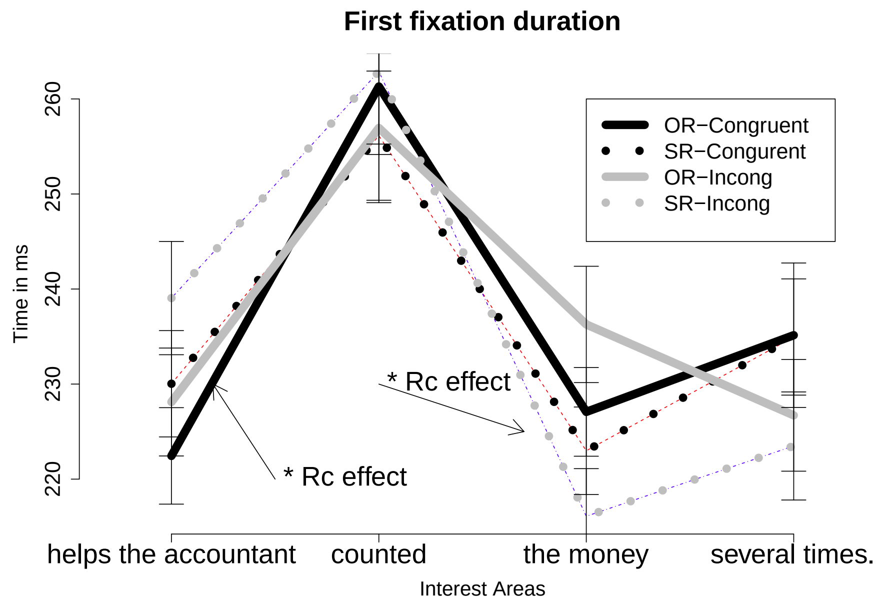
First-pass time is the duration from entering an area of interest for the first time until leaving it into any direction, again provided that this fixation was not preceded by a fixation on an interest region to the right.

Regression-path time is the duration of fixations from first entering the area of interest until a fixation to the right of the interest area, provided that this fixation was not preceded by a fixation on an interest area to the right. This measure includes all fixations (and saccades) that leave the interest area to the left and thus regress to a previous region. (Here it should be mentioned that regression-path times at the last region of a sentence might reflect processes of re-reading or regressions since the eye cannot pass this area to the right. Comparing regression-path time with the definition of go-past time earlier in the Introduction, both measures actually reflect the same reading times.)

Total reading time is the sum of all fixations on a region of interest. If successive fixations are in the same interest area, the saccades between fixations were included.

Figures 3 (first fixation duration), 4 (first-pass time), 5 (regression-path time) and 6 (total reading time) illustrate the reading time measures in ms on the different areas of interest. Table 13 shows the mean comprehension question errors for each condition. Tables 9 (first fixation duration), 10 (first-pass time), 11 (regression-path time), 12 (total reading time) and 14 (comprehension question errors) show the p- and F values of the by-subjects and by-items anova.

For the data analysis both analyses of variance with subjects (F1) and items (F2) as a random variable were conducted. Relative clause type and number congruency were collapsed across the number counterbalancing variable and treated as within subject and within item fixed variables. In addition, subject group was fixed between subject variables in the by-subject analyses and item group between item variable in the by-item analyses as described by Pollatsek and Well (1995).



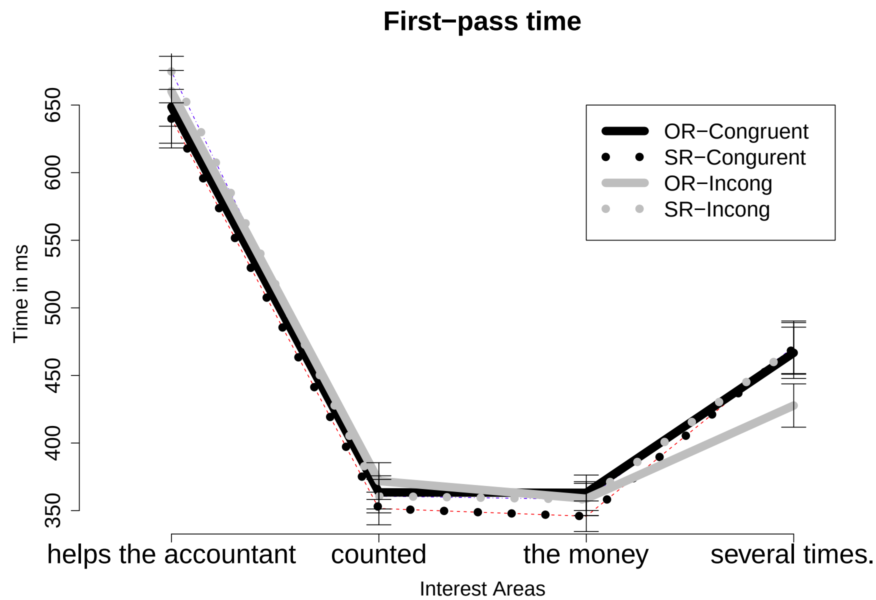
helps the accountant critical	counted spillover 1	the money spillover 2	several times final

conditions	critical	spillover 1	spillover 2	final
OR / congruent	222.44	261.31	227.08	235.14
SR / congruent	230.03	256.13	222.98	234.95
OR / incongruent	228.12	256.95	236.28	226.71
SR / incongruent	239.05	262.89	216.10	223.49

Figure 3: First fixation duration means in ms - Experiment 1

Table 9: F and p values for first fixation duration - Experiment 1

F1/F2	critical	spillover 1	spillover 2	final
Rel clause type				
F1(1,32)	**4.68**	<1	**3.90**	0.25
p	**.04**	.91	**.06**	.62
F2(1,24)	**5.19**	<1	**6.88**	0.26
p	**.03**	.98	**.01**	.61
nr congruency				
F1(1,32)	1.17	<1	<1	2.39
p	.29	.88	.80	.13
F2(1,24)	2.05	<1	<1	**3.35**
p	.17	.95	.96	**.08**
interaction:				
Rel clause × nr congruency				
F1(1,32)	<1	<1	**4.50**	<1
p	.91	.68	**.04**	.97
F2(1,24)	<1	<1	**3.41**	<1
p	.98	.80	**.08**	.93
Simple effects of nr cong: OR				
F1(1,32)	-	-	2.41	-
p	-	-	.13	-
F2(1,24)	-	-	1.46	-
p	-	-	.28	-
Simple effects of nr cong: SR				
F1(1,32)	-	-	2.57	-
p	-	-	.11	-
F2(1,24)	-	-	1.56	-
p	-	-	.22	-



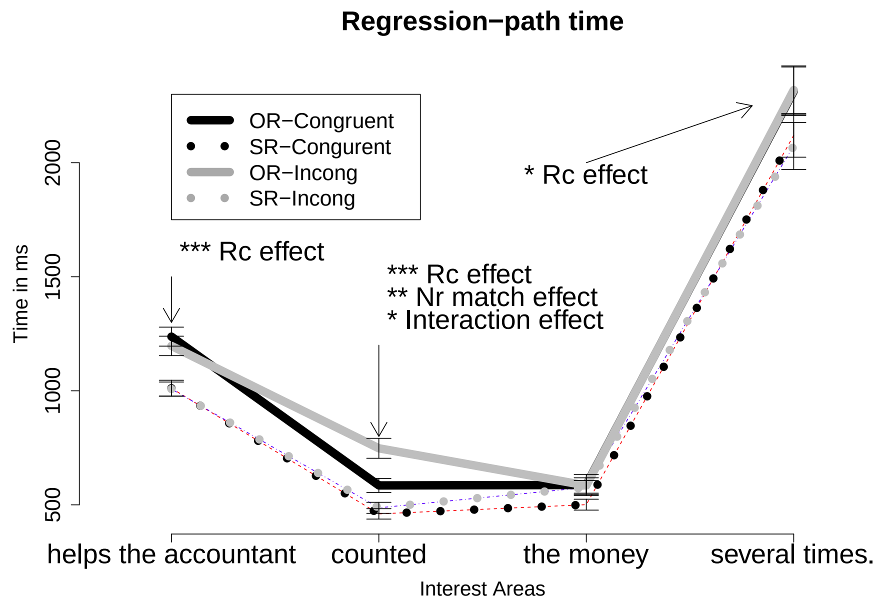
helps the accountant	counted	the money	several times
critical	spillover 1	spillover 2	final

conditions	critical	spillover 1	spillover 2	final
OR / congruent	648.71	363.51	363.19	466.75
SR / congruent	639.96	351.59	345.86	469.98
OR / incongruent	660.22	371.87	358.83	427.75
SR / incongruent	674.85	360.74	358.29	470.85

Figure 4: First-pass time means in ms - Experiment 1

Table 10: F and p values for first-pass time - Experiment 1

F1/F2	critical	spillover 1	spillover 2	final
Rel clause type				
F1(1,32)	<1	1.69	<1	1.56
p	.68	.20	.44	.22
F2(1,24)	<1	1.91	<1	<1
p	.70	.18	.39	.34
nr congruency				
F1(1,32)	<1	1.05	<1	2.13
p	.35	.31	.97	.15
F2(1,24)	1.15	1.51	<1	1.17
p	.29	.23	.97	.29
interaction:				
Rel clause type × nr congruency				
F1(1,32)	<1	<1	<1	2.05
p	.76	.70	.48	.16
F2(1,24)	<1	<1	<1	2.26
p	.89	.63	.65	.15



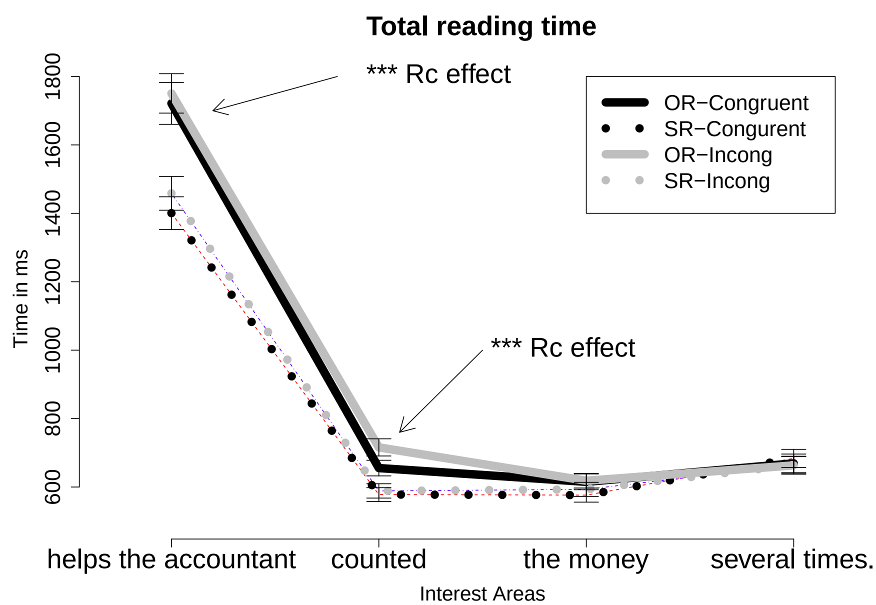
helps the accountant critical	counted spillover 1	the money spillover 2	several times final

conditions	critical	spillover 1	spillover 2	final
OR / congruent	1237.47	585.09	587.01	2313.60
SR / congruent	1011.08	460.31	500.76	2119.81
OR / incongruent	1196.73	747.89	584.84	2318.47
SR / incongruent	1007.73	486.92	576.28	2073.27

Figure 5: Regression-path time means in ms - Experiment 1

Table 11: F and p values for regression-path time - Experiment 1

F1/F2	critical	spillover 1	spillover 2	final
Rel clause type				
F1(1,32)	**33.03**	**32.68**	2.49	**7.02**
p	**<.001**	**<.001**	.12	**.01**
F2(1,24)	**35.89**	**57.42**	1.49	**4.18**
p	**<.001**	**<.001**	.23	**.05**
nr congruency				
F1(1,32)	<1	**9.75**	1.25	<1
p	.36	**<.001**	.27	.71
F2(1,24)	<1	**14.22**	<1	<1
p	.41	**<.001**	.43	.70
interaction:				
Rel clause × nr congruency				
F1(1,32)	<1	**5.80**	<1	<1
p	.75	**.02**	.37	.93
F2(1,24)	<1	**5.40**	<1	<1
p	.94	**.03**	.48	.99
Simple effects of nr cong: OR				
F1(1,32)	-	**8.94**	-	-
p	-	**<.01**	-	-
F2(1,24)	-	**12.22**	-	-
p	-	**<.001**	-	-
Simple effects of nr song: SR				
F1(1,32)	-	<1	-	-
p	-	.5224	-	-
F2(1,24)	-	<1	-	-
p	-	.3748	-	-



helps the accountant critical	counted spillover 1	the money spillover 2	several times final

conditions	critical	spillover 1	spillover 2	final
OR / congruent	1721.40	655.39	615.15	669.12
SR / congruent	1400.63	577.94	576.38	683.69
OR / incongruent	1750.55	715.86	618.37	663.263
SR / incongruent	1458.49	588.63	593.18	664.45

Figure 6: Total reading time means in ms - Experiment 1

Table 12: F and p values for total reading time - Experiment 1

F1/F2	critical	spillover 1	spillover 2	final
Rel clause type				
F1(1,32)	**30.95**	**25.11**	2.33	<1
p	**<.001**	**<.001**	.14	.77
F2(1,24)	**31.86**	**15.87**	1.50	<1
p	**<.001**	**<.001**	.23	.98
nr congruency				
F1(1,32)	<1	**3.41**	<1	<1
p	.37	**.07**	.70	.47
F2(1,24)	<1	2.96	<1	1.44
p	.50	.10	.83	.24
interaction:				
Rel clause type × nr cong				
F1(1,32)	<1	**3.44**	<1	<1
p	.92	**.07**	.86	.86
F2(1,24)	<1	1.85	<1	<1
p	.92	.19	.93	.89

Table 13: Means of comprehension question errors in Experiment 1

OR - congruent	SR - congruent	OR - incongruent	SR - incongruent
0.18	0.17	0.22	0.15

Table 14: F and p-values of comprehension question errors in Experiment 1

F / p	RC type	Nr congruency	Interaction RC type and Nr congruency
F1(1,32)	**3.04**	0.57	1.52
p	**.09**	.46	.23
F2(1,24)	**3.43**	0.09	1.70
p	**.08**	.76	.20

2.2.1 Analysis of the critical region: `helps the accountant / the accountant helps`

The analyses of variance showed a relative clause effect for first fixation duration on the critical region: $F1(1,32) = 4.68$, $p < .05$; $F2(1,24) = 5.19$, $p < .05$. The means for object relatives were longer than the means for subject relatives. The analyses of regression-path time also showed a main effect of relative clause: $F1(1,32) = 33.03$, $p < .005$; $F2(1,24) = 35.89$, $p < .005$. Reading times for object relatives were longer than for subject relatives. Total reading time at the critical region also showed an effect of relative clause: $F(1,32) = 30.95$, $p < .005$; $F2(1,24) = 31.86$, $p < .005$, indicating that object relatives took longer to read than subject relatives. The analysis of first-pass time did not show any significant effects at this region. There was no effect of number congruency at this region and no interaction effect between relative clause type and number congruency in any of the measures.

2.2.2 Analysis of the spillover 1 region: `counted`

Analyses of variance returned a main effect of relative clause type for the regression-path time measure in the spillover 1 region, $F1(1,32) = 32.68$, $p < .005$; $F2(1,24) = 57.42$, $p < .005$. The mean reading times for object relatives were longer than for subject relatives. The analyses also showed a main effect of number congruency for regression-path time, $F1(1,32) = 9.75$, $p < .01$; $F2(1,24) = 14.22$, $p < .01$. Reading times were longer when the noun phrases were incongruent than congruent in number. The incongruent conditions had longer regression-path times than the congruent conditions, the direction of this effect is opposite to the one predicted by the retrieval-cue parsing account. This congruency effect was modulated by an interaction between relative clause type and number congruency, $F1(1,32) = 5.80$, $p < .05$; $F1(1,24) = 5.40$, $p < .05$. Simple effects analyses for the object relatives showed that they took longer to read when the noun phrases were incongruent than congruent in number: $F1(1,32) = 8.94$, $p < .01$; $F2(1,24) = 12.22$, $p < .01$. In contrast, simple effects analyses for subject relatives showed that there was no difference between the congruent and incongruent conditions ($Fs < 1$). For the total reading time measure, there was a main effect of relative clause type at the spillover 1 region: $F1(1,32) = 25.11$, $p < .005$; $F2(1,24) = 15.87$, $p < .005$. Reading times for object relatives were longer than for the subject relatives.

In addition, the analyses of the total reading time measure showed a marginal effect by subjects of number congruency in the spillover 1 region $F1(1,32) = 3.41$, $p < .1$, but there was no effect by items $F2(1,24) = 2.96$, $p = .1$. Total reading times were longer when the noun phrases were incongruent in number than when they were congruent in number.

The interaction between relative clause type and number congruency showed a marginal effect by subjects only $F1(1,32) = 3.44$, $p < .1$ and no effect by items $F2(1,24) = 1.85$, $p = .19$.

Analyses of first fixation duration and first-path time did not show any main effects or effects of interaction between number congruency and relative clause type in this region.

2.2.3 Analysis of the spillover 2 region: `the money`

Analyses of first fixation duration returned a marginal effect by subjects for relative clauses: $F1(1,32) = 3.90$, $p < .1$ which was significant by items: $F2(1,24) = 6.88$, $p < .05$. The mean reading times of subject relatives were longer than for object relatives. This was modulated by an interaction which was significant by subjects $F1(1,32) = 4.50$, $p < .05$, but only marginal by items $F2(1,24) = 3.41$, $p < .1$. However, simple effects analysis showed that the effect of congruency in subject and object relatives were not significant. Thus, the relative clause effect was not modulated by an interaction.

Analyses of the first-pass duration, total reading time and regression-path time did not show any main effects or effects of interaction between number congruency and relative clause type in this region.

2.2.4 Analysis of the sentence final region: `several times`

An analysis of variance of the regression-path time measure showed a main effect of relative clause type in the final region. The effect was significant by subjects $F1(1,32) = 7.02$, $p < .05$, but only marginal by items $F2(1,24) = 4.18$, $p = .05$, with the object relatives being slower than the subject relatives. The analyses of the measures of first-pass time, total reading time and regression-path time did not show any effects. There was also no effect of interaction between number congruency and relative clause type in first fixation duration, first-pass time, regression-path time and total reading time.

2.2.5 Analyses of the comprehension question errors

The analyses of the comprehension question errors showed an effect of relative clause type, which was marginal by subjects $F1(1,32) = 3.04$, $p < .10$ and marginal by items $F2(1,24) = 3.43$, $p < .10$. The means showed that the object relative clause conditions had a higher error rate than the subject relative clause condition. There were no effects of number congruency in the comprehension question errors and no interaction between the two variables (relative clause type and number congruency).

2.3 Discussion of Experiment 1

Experiment 1 showed that object relatives were harder to process than subject relative clauses in the critical region (first fixation duration, regression-path time and total reading time), in the spillover 1 region (regression-path duration and total reading time) and at the final wrap-up region (regression-path time). The analysis of the comprehension questions showed that object relatives had a higher error rate, however this effect was only marginal by subjects and by items. There was no effect of relative clause type in first-pass time in any region.

Contrary to what is predicted by memory interference accounts, there was no evidence that the congruent conditions took longer to read than the incongruent conditions.

There was an effect of number congruency in regression-path times in the spillover 1 region (*counted*), with the incongruent number conditions being harder than the congruent number conditions. There was also an interaction effect between number congruency and relative clause type at the spillover 1 region (*counted*). The number congruent conditions had shorter reading times than the number incongruent conditions in the object relative conditions, while there was no effect of number congruency in the subject relative conditions.

The direction of these effects is opposite to that predicted by similarity based interference models (Van Dyke & Lewis, 2003; Lewis & Vasishth, 2005; Van Dyke & McElree, 2006), which claim that the number-congruent conditions should be more difficult. The integration of dissimilar noun phrases with their verb (maybe due to priming) seems more difficult than the integration of similar noun phrases. In addition, this difficulty spilled over to the next region. Most important, this suggests that similarity-based interference due to number congruency does not have a strong effect on the processing of subject or object-relative clauses.

3 Experiment 2

Experiment 1 showed an effect of relative clause type but no effect of number interference. It is possible that number interference does occur, but that in contrast to what is predicted by the similarity based interference account, it is a later effect. Number interference may occur after initial syntactic analysis of the relative clause, when readers check whether the verb also agrees with noun phrases other than the subject. This sort of mechanism is similar to the account put forward by Sturt (2003) for a delayed effect of inaccessible antecedents in anaphor resolution. Sturt (2003) argues that processes associated with this effect are not part of initial anaphor interpretation but later procedures like recovery and sentence wrap-up.

Because the region after the relative clause was relatively long in Experiment 1 *counted the money several times*, the retrieval interference effect due to cue overlap may be spread out over the region and difficult to detect. Therefore, the final region after the relative clause was shortened in Experiment 2. The same materials as in Experiment 1 were tested without the final region (e.g., *several times*).

1. (a) **subject-relative / nr congruent**
    - i. The banker that helps the accountant counted the money.
    - ii. The bankers that help the accountants counted the money.

   (b) **subject-relative / nr incongruent**
    - i. The bankers that help the accountant counted the money.
    - ii. The banker that helps the accountants counted the money.

2. (a) **object-relative / nr congruent**
    - i. The banker that the accountant helps counted the money.
    - ii. The bankers that the accountants helps counted the money.

   (b) **object-relative / nr incongruent**
    - i. The bankers that the accountant helps counted the money.
    - ii. The banker that the accountants help counted the money.

3.1 Method

3.1.1 Participants

The number of participants and the selection criteria for the participants in Experiment 2 were the same as in Experiment 1.

Table 15: Experiment 2: Areas of interest

	1	critical	spillover	wrap-up
SR	The banker(s) that	help(s) the accountant(s)	counted	the money.
OR	The banker(s) that	the accountant(s) help(s)	counted	the money.

3.1.2 Materials

Experiment 2 was an eye-tracking experiment with the same 2×2×2 design as described for Experiment 1. The experimental items were sentences with an embedded relative clause: `subject` + `relative clause` + `verb phrase`. The relative clause (variable 1) was either a subject relative (`verb` + `noun`) or an object relative (`noun` + `verb`). Like in Experiment 1, the subject noun and the embedded noun were either both singular or both plural (the same in number) or one was singular and the other was plural (different in number). Thus, like in Experiment 1 number congruency was the second variable in Experiment 2. Finally, counterbalancing of the noun phrase number was variable 3 in Experiment 2.

The example shows a sample experimental item and Table 15 the interest areas that were analysed in Experiment 2. The sentences were shorter than in Experiment 1. The area of interest that was the spillover 2 region in Experiment 1 (*the money*), is now the wrap-up region. The former wrap-up region was removed for Experiment 2. Like in Experiment 1, the spillover region (*counted*) was at least 7 letters long and so was the wrap-up region.

The comprehension questions and the fillers were the same as in Experiment 1. However, due to a mistake in the experimental setup, no data about the comprehension question accuracy was collected. Therefore, comprehension question errors could not be analysed for Experiment 2.

3.1.3 Design

Experiment 1 had the same design as Experiment 2.

3.1.4 Apparatus and procedure

The same apparatus and procedure from Experiment 1 were used in Experiment 2.

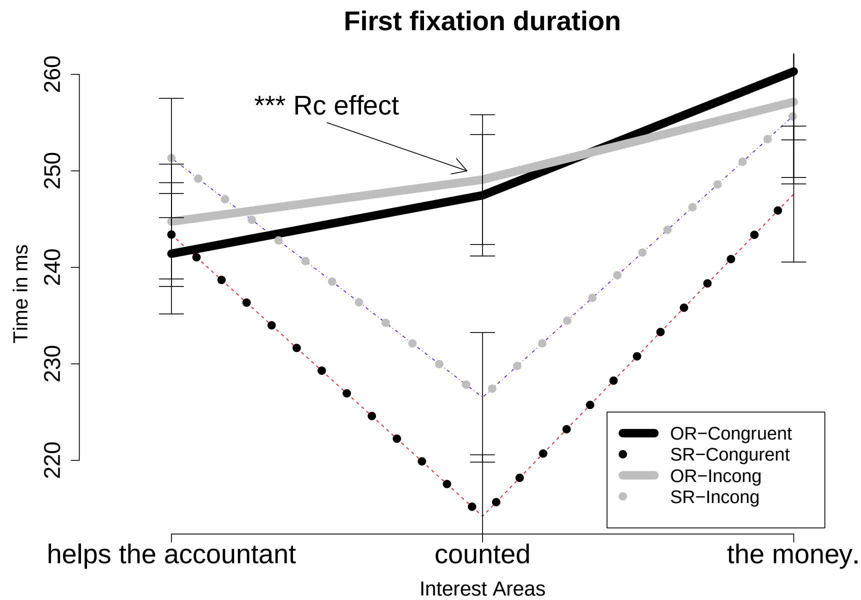
3.2 Results

The analyses of variance followed the same procedure as in Experiment 1. The areas of interest for the analysis were the critical region, spillover and the sentence wrap-up region (see Materials).

The Figures 7, 8, 9 and 10, illustrate the reading time measures: first fixation duration (7), first-pass time (8), regression-path time (9) and total reading time (10). The reading times are shown for the different areas of interest: the critical area (`helps the accountant`), the spillover region (`counted`) and the sentence wrap-up region (`the money.`). The Tables 16 (first fixation duration), 17 (first-pass time), 18 (regression-path time) and 19 (total reading time) show the p- and F values of the by-subjects and by-items anova for Experiment 2.

3.2.1 Analysis of critical region: `helps the accountant / the accountant helps`.

Regression-path time showed a main effect of relative clause type in the critical interest area: $F1(1,32) = 17.81$, $p < .005$; $F2(1,24) = 16.91$, $p < .005$. Mean reading times for object relatives were longer than for subject relatives. Total reading time measure also showed a main effect of relative clause type in the critical interest area $F1(1,32) = 46.07$, $p < .005$; $F2(1,24) = 31.80$, $p < .005$. Reading times for object relatives were longer than for subject relatives. There was no effect of relative clause type in first fixation duration



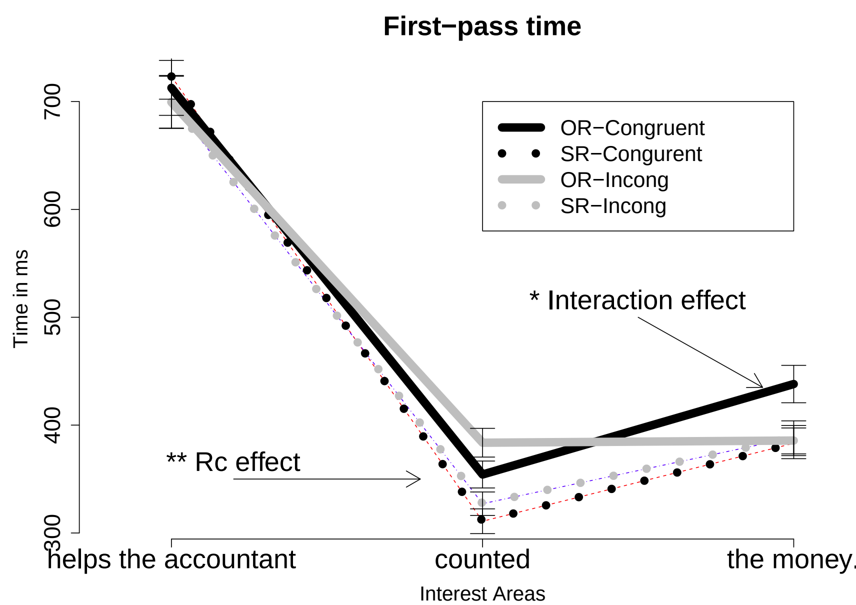
helps the accountant	counted	the money
critical	spillover	final

conditions	**critical**	**spillover**	**final**
OR / congruent	241.41	247.47	260.30
SR / congruent	243.40	214.21	247.59
OR / incongruent	244.74	249.09	257.15
SR / incongruent	251.33	226.53	255.74

Figure 7: First fixation duration means in ms - Experiment 2

Table 16: F and p values for first fixation duration - Experiment 2

F1/F2	critical	spillover	final
Rel clause type			
F1(1,32)	<1	**16.35**	<1
p	.60	<**.001**	.51
F2(1,24)	<1	**10.66**	<1
p	.70	<**.001**	.48
nr congruency			
F1(1,32)	1.18	<1	<1
p	.29	.50	.76
F2(1,24)	<1	<1	<1
p	.63	.37	.91
interaction:			
Rel clause type × nr cong			
F1(1,32)	<1	<1	1.36
p	.58	.51	.25
F2(1,24)	<1	1.12	<1
p	.56	.30	.67



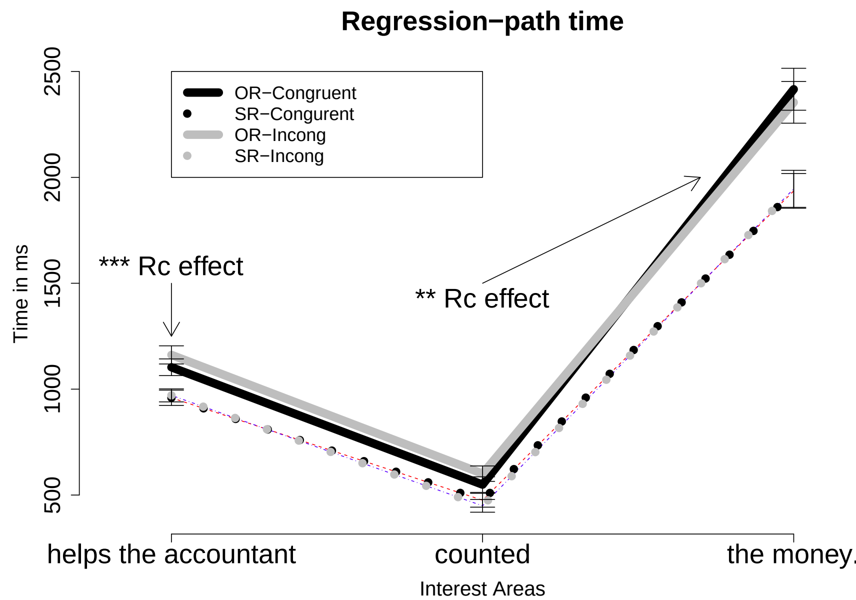
helps the accountant	counted	the money
critical	spillover	final

conditions	**critical**	**spillover**	**final**
OR / congruent	712.68	354.22	438.08
SR / congruent	723.24	310.89	383.13
OR / incongruent	699.42	383.70	385.70
SR / incongruent	699.63	327.15	388.65

Figure 8: First-pass time means in ms - Experiment 2

Table 17: F and p values for first-pass time - Experiment 2

F1/F2	critical	spillover	final
Rel clause type			
F1(1,32)	<1	**8.95**	**3.41**
p	.81	<**.01**	**.07**
F2(1,24)	<1	**8.65**	1.97
p	.71	<**.01**	.17
nr congruency			
F1(1,32)	<1	2.58	**4.42**
p	.34	.12	**.04**
F2(1,24)	<1	2.03	2.51
p	.57	.17	.13
interaction:			
Rel clause type × *nr cong*			
F1(1,32)	<1	2.32	**4.10**
p	.77	.14	**.05**
F2(1,24)	<1	2.03	**4.91**
p	.94	.17	**.04**
Simple effects of nr cong: OR			
F1(1,32)	-	-	**6.20**
p	-	-	**.02**
F2(1,24)	-	-	**5.97**
p	-	-	**.02**
Simple effects of nr cong: SR			
F1(1,32)	-	-	<1
p	-	-	.68
F2(1,24)	-	-	<1
p	-	-	.90



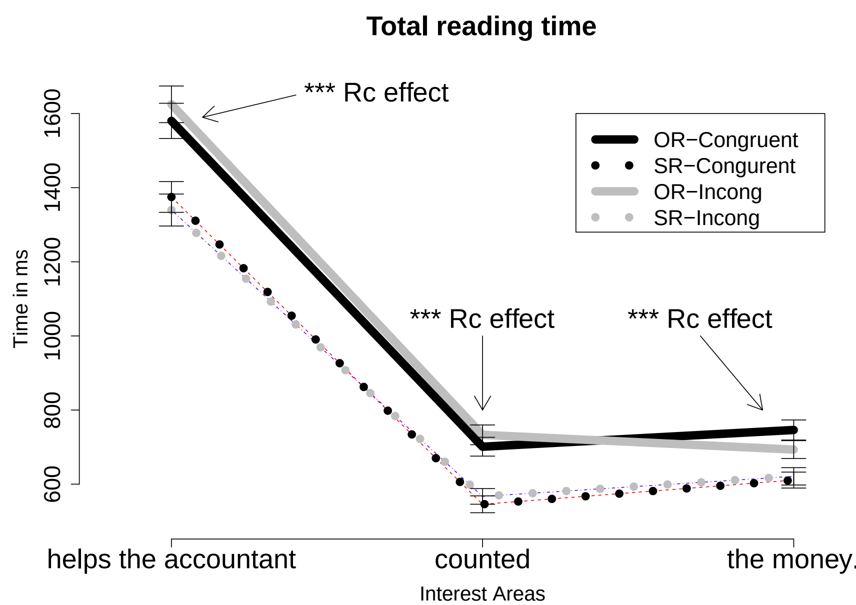
helps the accountant	counted	the money
critical	spillover	final

conditions	**critical**	**spillover**	**final**
OR / congruent	1103.48	549.37	2416.02
SR / congruent	959.30	475.51	1936.18
OR / incongruent	1161.80	601.11	2354.32
SR / incongruent	970.72	449.18	1945.87

Figure 9: Regression-path time means in ms - Experiment 2

Table 18: F and p values for regression-path time - Experiment 2

F1/F2	critical	spillover	final
Rel clause type			
F1(1,32)	**17.81**	**6.23**	**22.76**
p	**<.001**	**.02**	**<.001**
F2(1,24)	**16.91**	**3.81**	**10.70**
p	**<.001**	**.06**	**<.001**
nr congruency			
F1(1,32)	1.40	<1	<1
p	.25	.95	.94
F2(1,24)	<1	<1	<1
p	.50	.68	.85
interaction:			
Rel clause type × nr cong			
F1(1,32)	<1	1.38	<1
p	.52	.25	.50
F2(1,24)	<1	1.61	<1
p	.81	.22	.56



helps the accountant critical	counted spillover	the money final

conditions	critical	spillover	final
OR / congruent	1580.23	701.06	746.22
SR / congruent	1374.90	545.74	611.02
OR / incongruent	1624.86	733.09	693.35
SR / incongruent	1339.68	566.96	621.15

Figure 10: Total reading time means in ms - Experiment 2

Table 19: F and p values for total reading time - Experiment 2

F1/F2	critical	spillover	final
Rel clause type			
F1(1,32)	**46.07**	**39.00**	**18.63**
p	**<.001**	**<.001**	**<.001**
F2(1,24)	**31.80**	**26.94**	**16.88**
p	**<.001**	**<.001**	**<.001**
nr congruency			
F1(1,32)	<1	1.74	<1
p	.85	.20	.39
F2(1,24)	<1	1.60	1.23
p	.79	.22	.28
interaction:			
Rel clause type × nr cong			
F1(1,32)	1.33	<1	2.26
p	.26	.42	.14
F2(1,24)	<1	<1	2.61
p	.57	.40	.12

and first-pass time. There was also no effect of number congruency in this region in first fixation duration, first-pass time, regression-path time and total reading time. Finally, no interactions between number congruency and relative clause type were observed in first fixation duration, first-pass time, regression-path time and total reading time.

3.2.2 Analysis of the spillover region: `counted`.

First-pass time showed a main effect of relative clause type at the spillover region $F1(1,32) = 8.95$, $p < .01$; $F2(1,24) = 8.65$, $p < .01$: object relatives took longer than subject relatives.

Regression-path time showed an effect of relative clause type by subjects $F1(1,32) = 6.24$, $p < .05$; this effect was marginal by items $F2(1,24) = 3.4$, $p < .1$. Object relatives had longer reading times than subject relatives.

Analyses of total reading time for the spillover region showed a significant main effect of relative clause type $F1(1,32) = 39.00$, $p < .005$; $F2(1,24) = 26.94$, $p < .005$. Mean reading times for object relatives were significantly longer than for subject relatives.

There was no effect of number congruency in first fixation duration, first-pass time, regression-path time and total reading time on the spillover region. There was also no interaction effect between relative clause type and number congruency in first fixation duration, first-pass time, regression-path time and total reading time.

3.2.3 Analysis of the final sentence wrap-up region: `the money`.

In first-pass time, there was a marginal effect of the relative clause by subjects: $F1(1,32) = 3.41$, $p < .1$ but no effect by items $F2(1,24) = 1.97$, $p < .15$: object relatives had longer reading times than subject relatives. There was also a significant effect of number congruency in first-pass time by-subjects: $F1(1,32) = 4.42$, $p < .05$ but not by items $F2(1,24) = 2.51$, $p < .15$. Number congruent conditions had longer first-pass times than the number incongruent conditions.

Most importantly, there was an interaction between relative clause type and number congruency in first-pass time: F1(1,32) = 4.10, $p = .05$; and F2(1,24) = 4.91, $p < .05$. Simple effect analyses for object relative clauses showed that object relatives that were congruent in number had longer reading times than object relatives with noun phrases incongruent in number: F1(1,32) = 6.20, $p < .05$; F2(1,24) =5.97, $p < .05$. Simple effect analyses for subject relatives showed that there was no difference between congruent and incongruent noun phrases in subject relatives (Fs < 1).

In the total reading time measure, an effect of relative clause was observed: F1(1,32) = 18.63, $p < .005$; F2(1,24) = 16.88, $p < .005$. Object relatives took longer to read than subject relatives. Regression-path time showed a main effect of relative clause F1(1,32) = 22.76, $p < .005$; F2(1,24) = 10.70, $p < .005$. Mean reading times for object relatives were longer than for subject relatives.

No effect of relative clause type was observed for first fixation duration at the sentence wrap-up region. There was also no effect of number congruency for first fixation duration, regression-path time and total reading time.

3.3 Discussion of Experiment 2

As predicted by similarity based memory interference accounts object-relative clauses were significantly more difficult to process than subject-relative clauses. There were main effects of relative-clause type for total reading time and regression-path time at the critical, the spillover and the sentence wrap-up region. Early measures like first fixation duration and first-pass time showed a main effect at the spillover region.

The effect of number retrieval cue overlap was observed late as an interaction with relative clause type at the final sentence wrap-up region. While the Van Dyke and Lewis (2003) predict retrieval cue overlap to cause a retrieval interference effect, it is unclear (1.) Why would this appear separate from the interference effect due to relative clause type? and (2.) Why is it such a late effect?

According to Lewis (1996); Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) there should be an interference effect at the embedded verb (*helps*) in the object relative clause. This interference effect is caused by an interfering noun phrase (*accountant*) that is stored in memory in addition to the target subject (*banker*). In comparison, there should be no interference effect at the embedded verb in subject relative clauses because there is no interfering noun in memory at the point of verb integration in subject relatives. Lewis (1996); Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) predicted that the similarity between the noun phrases in memory affects the retrieval of the subject in object relatives. When the verb needs to be integrated with its subject, a retrieval probe matches retrieval cues of the verb with those items in memory. The verb integration should be even more difficult in the object relative condition when the interfering noun phrase shares retrieval cues with the target subject. Therefore, the account of Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) predicted that the relative clause effect and the number congruency effect both should have been observed during the integration of the embedded verb (*helps*).

Several explanations for this observation are possible. It might simply be that the relative clause difference is not a similarity-based interference effect and the actual interference effect shows at a later point.

The findings of a late number interference effect can be related to Van Dyke (2007). Van Dyke reported a delayed semantic interference effect on the sentence wrap-up region when they investigated semantic and syntactic memory interference. She contrasted high- (b) and low-complex (a) syntactic sentences (with or without an additional embedded relative clause) and more or less semantically interfering constructions (the critical verb (*moaned*) is preceded by a noun that can either function as possible subject (*man*) or not (*seat*)).

1. (a) **low-complex sentence**
   The pilot remembered that the lady who was sitting in/near the smelly *seat/man* yesterday afternoon moaned about a refund for the ticket.

   (b) **high-complex sentence**
   The pilot remembered that the lady who said that the *seat/man* was

smelly yesterday afternoon moaned about a refund for the ticket.
(Van Dyke, 2007, p. 418)

At the position of verb integration (*moaned*), which should prompt the retrieval of the noun phrase (*lady*), Van Dyke (2007) found an early syntactic effect. The effect of the preceding noun (the preceding noun either was a semantically plausible candidate a the subject (*man*) of the verb (*moaned*) or not (*seat*).) showed up as a delayed effect on the sentence wrap-up region (*for the ticket*). Current models of similarity based interference fail to account for such a time delay. The retrieval cue based parsing account predicts an interference effect when verb integration at *moaned* prompts the retrieval of the noun phrases in memory.

To account for this discrepancy, (Van Dyke, 2007) argued that there might be additional reanalysis processes causing the delay. It might be that *man* is erroneously interpreted as the subject of the following verb and this might initiate a reanalysis process that occurs at a later point independent from the syntactic effect. However, since *seat* cannot be the subject of *moaned*, an additional reanalysis could only delay the animate condition. Thus, this argument that the delay of the interference effect might have been driven by additional reanalysis is unclear.

4 General Discussion of Experiments 1 and 2

Both Experiments 1 and 2 showed that subject relatives are more difficult than object relatives. This effect was found in the critical region (in Experiment 1 for regression-path and total reading time; in Experiment 2 for total reading time). However, neither Experiment 1 nor Experiment 2 found evidence for number interference in early measures. In Experiment 1, sentences with congruent nouns were easier than with incongruent nouns. In Experiment 2, there was evidence for number interference in object relatives, but this occurred during later processing, in the final region.

The observed delay of the number congruency effect in comparison to the relative clause effect in Experiment 2 is not consistent with memory interference models. They predict the number congruency effect to occur at the relative clause region, simultaneously with the slow-down for the object relative clause conditions. Instead, the results suggest that the number congruency effect is part of integrative processing that occurs in cases where the sentence is structurally complex, i.e. in object relatives. While memory interference accounts for both the syntactic (relative clause effect in both experiment) and the number cue overlap effect (the observed interaction in the second experiment) it fails to explain the delay of the number interference effect. At the point of verb integration, the retrieval of the verb dependent should be more difficult in the object relative condition because there are two items in memory. In addition to the number of items in memory, the similarity between these nouns (either they have the same number information or their number differs) should make their retrieval more difficult. Therefore, both the syntactic (relative clause) and the interference effect due to the overlap of other cues (e.g., number) interference should affect the integration of the verb and this effect should have been observed simultaneously. It should be observed early, assuming that construction of syntax happens early. This was not the case for our two experiments where the number interference effect was observed at the final wrap-up region independent from the syntactic effect (Experiment 2) or not at all (Experiment 1).

The results suggest that the retrieval interference effect is an integrative process that does not arise during structure building. One possibility is that it is due to a checking process that occurs when a sentence is structurally complex as is the case with object relatives. Since it occurred after the relative clause region, it might have been spread out over the long final region in Experiment 1 and therefore hard to detect. In Experiment 2, it was condensed to a single region.

The materials in both Experiment 1 and 2 contained a tense mismatch between the embedded verb (*helps*[present]) and matrix verb (*counted*[past]), which might have made them difficult to understand. This difficulty might have potentially masked interference effects. However, when using the same verb forms and shortening the final regions in Experiment 2, there was an interference effect at the final region of the sentence. Thus, it is assumed that the interference effect was weak and spread over the long final region in Experiment 1, but could be observed with a shorter final region in Experiment 2.

Upon first glance, the results seem to support the findings of Van Dyke (2007) with an early syntactic effect (our findings: relative clause effect) and a late effect in number congruency. With a closer look at the experiments it seems the explanation for the findings in Van Dyke cannot explain the delay in our experiments.

Overall, the number interference effect was observed only at the final region in first-pass time of Experiment 2, which might also suggest that number interference is not a strong effect in sentence processing.

However, number interference might be marked by agreement processes between a local noun and a verb that are mismatching in number. Number production studies showed (Bock & Miller, 1991; Bock & Cutting, 1992) that when a subject is followed by a prepositional phrase, the following verb is likely to agree in number with a preceding noun (that is mismatching in number) instead of with its actual subject. Agreement errors like those in (a) are more likely than errors in (b).

(a) * The key to the cabinets were on the table.

(b) * The keys to the cabinet was on the table.

Thus, in production, people sometimes produce a verb that agrees with the local incorrect noun. If this also affects comprehension how would this affect reading?

5 Number Agreement in Sentence Processing (Production and Comprehension)

Agreement is a grammatical tool to highlight what pieces in a sentence belong together. In English, agreement is used in two ways: pronoun agreement and subject verb agreement. Agreement processes link pronouns with their antecedents (Bock, Nicol, & Cutting, 1999). Consider the sentence: *The girl hoped her dreams would come true.* The pronoun *her* is signalling a female antecedent and therefore refers to *the girl*. Thus, the pronoun (*her*) links *the dreams* to *the girl*. In a different scenario: *The boy and the girl hoped his dreams would come true.* The pronoun *his*, since it is signalling a male antecedent, refers to the *boy* instead of the *girl*. Thus, the agreement between a pronoun and its antecedent highlights their connection and thus links them (in the latter case *the boy* and *his dreams*) together in a sentence. In addition, agreement is also used to link subjects with their verbs by means of number marking. For example in: *the teacher*$_{sing}$ *speaks*$_{sing}$, both the subject *the teacher* are in singular and therefore the verb *speaks* needs to be in singular. If the subject would be plural (*the teachers*) the verb would need to agree and be in plural form too (*speak*).

Number agreement processes are regularly challenged. This results in number agreement errors that are often observed in spoken utterances like the following: *The time for fun and games are over.* (Bock & Miller, 1991, p. 46). This type of grammatical error in language production is called *attraction* and occurs when a verb erroneously agrees in number with a preceding noun phrase that is not its subject.

5.1 The number attraction effect in production

In the English language, a subject noun and its verb need to agree in number. This means that when a subject noun (e.g. *the teachers*$_{pl}$) is plural, its verb should be plural (e.g. *the teachers*$_{pl}$ *supervise*$_{pl}$) and when the subject is singular (e.g. *the teacher*$_{sing}$) its verb should also be singular (*the teacher*$_{sing}$ *supervises*$_{sing}$). Even though, number agreement is syntactically straightforward, Bock and Miller (1991) argued that speakers sometimes violate agreement operations in language production. Consider a case where there is an intervening region between a singular subject and its verb and this intervening region might contain a plural noun in (1). At times, speakers tend to produce a verb that erroneously agrees with the number of the plural intervening noun instead of with the singular subject noun. Sentence

(1) is an example for such an error from spoken English. The verb *are* is in plural even though its actual subject *time* is in singular and therefore the verb should be singular (*is*) too. The number of the verb erroneously agrees with the local noun *games*, which is plural.

1. **number attraction error**
   The time for fun and games are over.
   (Bock & Miller, 1991, p. 46)

Bock and Miller (1991) investigated whether these effects could also be observed in an experimental setting.

In an experiment by Bock and Miller (1991), participants listened to sentence preambles with two noun phrase connected by the preposition *to* like those in (2). They had to repeat this preface and continue to finish the sentence. Bock and Miller manipulated the length of the intervening region before the verb and contrasted conditions that had a long intervening region in (2b) with conditions that had a short intervening region in (2a). The number of the two noun phrases (*key*, *cabinet*) was counterbalanced: the head noun phrase was either plural or singular. The noun phrase *cabinet* is the local noun phrase (speakers were expected to produce a verb directly after *cabinets* - thus *cabinets* is the local noun phrase) and was either plural or singular. Bock and Miller predicted agreement errors for the conditions when the head noun is singular and the local noun is plural in (2ai) and in (2bi). According to Mann (1982) a longer region intervening between the verb and its subject should increase the likelihood that an agreement error occurs. Mann argued that memory factors affect production and therefore the number information of the subject might have simply been forgotten over a longer region. That's why Bock and Miller predicted that there should be more agreement errors for the conditions with a singular subject and a plural local noun that have a long intervening region before the verb in (2bi).

2. **noun phrases**

   (a) **short region**

i. **mismatch: singular subject / plural local**
The key to the cabinets

ii. **mismatch: plural subject / singular local**
The keys to the cabinet

iii. **match: singular subject / singular local**
The key to the cabinet

iv. **match: plural subject / plural local**
The keys to the cabinets

(b) **long region**

i. **mismatch: singular subject / plural local**
The key to the ornate Victorian cabinets

ii. **mismatch: plural subject / singular local**
The keys to the ornate Victorian cabinet

iii. **match: singular subject / singular local**
The key to the ornate Victorian cabinet

iv. **match: plural subject / plural local**
The keys to the ornate Victorian cabinets

Bock and Miller (1991) reported that, overall, the mismatching conditions (2ai, 2aii, 2bi, 2bii) elicited more agreement errors than the matching conditions (2aiii, 2aiv, 2biii, 2biv). There were more agreement errors after a local plural than after a local singular noun. Thus, speakers were more likely to produce a verb that erroneously agreed with the local noun when this local noun is plural (e.g. *cabinets*) and the head noun is singular (e.g. *key*) than when the local noun is singular (e.g. *cabinet*) and the subject head is plural (e.g. *keys*). The length of the intervening region did not affect whether speakers made an agreement error: the short intervening conditions (2ai - iv) and the long intervening conditions (2bi - iv) had the same rate of agreement violations.

In addition to the prepositional phrases, Bock and Miller (1991) also tested whether relative clauses can cause agreement errors. In Example (3) a relative clause (*that liked the snakes*) separated the subject (*The boy*) from the verb which participants were asked to produce after the preamble. The intervening relative clause is longer and more complex than the prepositional phrase conditions described in Example (2). Bock and Miller predicted that agreement errors should also be observable when the head subject and its verb get separated by a relative clause. The sentences in Example (3) were tested together with the prepositional phrase conditions.

3. (a) **short region**
    i. **mismatch: singular subject / plural local**
    The boy that liked the snakes
    ii. **mismatch: plural subject / singular local**
    The boys that liked the snake
    iii. **match: singular subject / singular local**
    The boy that liked the snake
    iv. **match: plural subject / plural local**
    The boys that liked the snakes
   (b) **long region**
    i. **mismatch: singular subject / plural local**
    The boy that liked the colorful garter snakes
    ii. **mismatch: plural subject / singular local**
    The boys that liked the colorful garter snake
    iii. **match: singular subject / singular local**
    The boy that liked the colorful garter snake
    iv. **match: plural subject / plural local**
    The boys that liked the colorful garter snakes
    (Bock & Miller, 1991)

The mismatch conditions had more agreement errors than the match conditions. In addition, Bock and Miller found that relative clause constructions also elicited agreement errors at the verb. However, Bock and Miller found that while both prepositional and relative clause constructions elicited agreement errors, there were significantly more errors after a prepositional phrase than after a relative clause.

This finding is in line with Bock and Cutting (1992), who investigated whether the effects of number attraction are a consequence of either serial or hierarchical production planning principles. In a serial planning account, a subject is kept in memory over an intervening region until it can be integrated with its verb. The specification of the subject precedes the specification of the verb. The hierarchical account, on the other hand, claims that the subject and the verb are concurrently specified. Thus, if the subject and verb form are planned in parallel, the intervening region should affect the likelihood of attraction errors differently. In a prepositional phrase, the subject and the verb are separated by a noun that is related to the subject (*editors of the history book* in (4a)). In a relative clause, subject and verb are separated by a clause (*who rejected the book* in (4b)), the embedded object noun that precedes the main verb is only indirectly related to the sentence subject.

According to the serial account both the relative clause and the prepositional phrase conditions should elicit a similar amount of attraction errors since the length of the intervening region is the same for both conditions. However, the hierarchical planning account predicted fewer agreement mistakes after the relative clause than after the prepositional phrase. A functional level in the hierarchical account, integrates single words into a syntactic structure. Therefore, the structure of the intervening region should affect attraction processes. By embedding *books* in a relative clause, it is syntactically separated from the verb that participants were asked to produce. Since the local number attractor noun is syntactically separated from the verb, the hierarchical account predicts fewer attraction errors in the relative clause conditions in (5) than the prepositional phrase condition in (4). Bock and Cutting (1992) tested this in a production study contrasting sentence preambles containing prepositional phrases (4) with sentence preambles containing relative clauses (5).

4. **prepositional phrase**

   (a) **mismatch / singular local**
   The editors of the history book

(b) **mismatch / plural local**
The editor of the history books

(c) **match / singular local**
The editor of the history book

(d) **match / plural local**
The editors of the history books

5. **relative clause**

   (a) **mismatch / singular local**
   The editors who rejected the book

   (b) **mismatch / plural local**
   The editor who rejected the books

   (c) **match / singular local**
   The editor who rejected the book

   (d) **match / plural local**
   The editors who rejected the books
   (Bock & Cutting, 1992, p. 106)

The number of attraction errors for sentences like in Example (4) and (5) confirmed the findings of Bock and Miller (1991). There were more agreement errors in the mismatch (4a,4b,5a,5b) than in the match conditions (4c,4d,5c,5d) and more agreement errors were produced after plural local (4b,4d,5b,5d) than after a singular local noun (4a,4c,5a,5c). More importantly, however, there were significantly more errors in the prepositional phrase conditions in (4) than in the relative clause conditions in (5). These findings are more in agreement with the hierarchical language production account and challenge theories of serial language production. (Bock & Cutting, 1992)

Thus, Bock and Miller (1991) and Bock and Cutting (1992) demonstrated that agreement errors can be observed in an experimental setting. Furthermore, when in the mismatching conditions the head noun is plural and the local noun is singular, the main verb is less likely to erroneously agree with the local singular noun. The finding that there are more attraction errors when the local noun phrase is plural than when the local noun phrase is singular in mismatching prepositional phrases is interesting. Eberhard (1997) argued that this asymmetry effect is due to a special status of plural noun phrases in comparison with singular noun phrases. According to Eberhard plural noun phrases possess a grammatical feature for number and are therefore marked, whereas singular noun phrases lack these features and are unmarked. Thus, number agreement follows different processes for plurality and singularity: while the agreement with singular nouns is set to default, plural agreement is initiated by unambiguous number information. Therefore, the presence of a local plural noun would implement number agreement processes. Nevertheless, a sentence preamble that contains a local singular noun and a plural subject noun can cause more attraction errors at the verb (people would erroneously produce a singular verb) than matching conditions.

5.1.1 The production syntax account

The findings of Franck, Vigliocco, and Nicol (2002) and Franck, Lassi, Frauenfelder, and Rizzi (2006) suggest that a number attractor does not necessarily have to directly precede the verb in order to cause a number attraction effect. According to their production syntax approach any noun that occurs in the region separating a subject from its verb can interfere with the agreement processes of the verb. When there is more than one noun in the interfering region between a subject and a verb, the production syntax predicts that the noun which is higher in the syntactic tree has a bigger effect on the agreement processes than the noun which is lower in the syntactic tree. In addition, the position of the attracting noun in the syntactic tree should play a bigger role than its recency to the verb.

Franck et al. (2002) tested these predictions in a production experiment where participants had to continue the preamble of a prepositional phrase with three noun phrases (6). In (6b) the number attractor *experiments* directly precedes the verb. In (6a) the number attractor *programs* is more distant in terms of location. However, syntactically it is closer to the verb since the second noun of these three noun phrases is higher in the syntactic structure. A number attractor that is syntactically closer to the verb is said to be more likely to c-command the verb or serve as the subject for the verb.

Thus, *programs* is more likely to c-command the verb than *experiments* and should cause more attraction errors. C-command is a syntactic relation of dominance in phrase-structure grammar. In a sentence a subject dominates its verb, which in turn dominates its object. Franck et al. argued that a noun that is higher in the syntactic tree has a stronger c-command control over the verb. If the verb needs to be directly preceded by a number attractor to cause an agreement error then there should be more production errors on the following verb in (6b) than in (6a). However, if, as Franck et al. (2002) argued, the c-command relation should have a bigger effect on agreement processes then it is (6a) that will show more agreement errors on the produced verb.

6. (a) The computer with the programs of the experiment ...
   (b) The computer with the program of the experiments ...

Franck et al. (2002) reported more attraction errors (**The computer with the programs of the experiment are broken.*) when the plural noun phrase was high up in the syntactic tree structure (*programs* 6a) than when the plural attractor noun is low in the tree structure (*experiments* 6b). Thus, Franck et al. argued that because syntactic processes affect agreement errors, the number attractor does not necessarily have to directly precede the verb for an agreement error to occur.

Franck et al. (2006) reported another production study that shows how syntactic relations affect agreement processes. Franck et al. argued that agreement processes are more interfered with if the attracting noun c-commands the produced verb. To test this, Franck et al. described a production study which was conducted in French. As an example in (7), the object pronoun (*les "them"*) intervenes between the subject and the verb (7a) while in (7b) a subject modifier noun (*élèves "students"*) comes between the subject and its verb. If syntactic dominance as described by the c-command relation plays a role, (7a) should result in more attraction errors than (7b). *Le professeur "The professor"* c-commands the *les "them"* and *lisent "read"* in (7a). In contrast, the interfering item *les élèves "the students"* in (7b) is c-commanded by the subject, but it does not c-command the verb since *des élèves* is a subject complement.

7. (a) Le professeur les lit / *lisent.
   (The professor them reads / *read.)

   (b) Le professeur des élèves lit/*lisent.
   (The professor of the students reads / *read.)
   (Franck et al., 2006, p. 190)

Franck et al. (2006) reported more agreement errors for condition (7a) than for condition (7b). Thus, the noun that c-commanded the verb (*les / them*) caused more attraction errors than the attractor (*des élèves / the students*) that merely preceded the verb. Franck et al. (2002) and Franck et al. (2006) claimed that a plural noun is more likely to cause an attraction effect if it is either syntactically closer to the verb and thus c-commands the verb. Each of these syntactic relations are stronger than a pure recency effect, which means that an attractor does not need to be immediately preceding the verb in order to cause an agreement error.

5.1.2 A semantic integration hypothesis

The previous studies by Franck et al. (2002, 2006) showed how the syntactic relations between the subject, the verb and the number attractors in the interfering region affect agreement processes. Solomon and Pearlmutter (2004) described an account which considers semantic factors in the attraction effect: the *activation-based system*. According to an activation based approach, the coordination of the prepositional phrase *the drawing of the flowers*, involves the construction of the phrase (NP+PP) where each word will be incorporated into the structure. Solomon and Pearlmutter claimed that words will be integrated simultaneously and thus the phrase construction is a parallel process, which in turn, uses memory resources and is difficult. The parallel integration of the NP and the PP should be especially difficult if the noun phrases in the prepositional phrase are closely integrated with each other. Two noun phrases are semantically closely integrated with each other when one noun phrase somehow describes the relationship to the other. For example in *the bracelet made of silver* (Solomon & Pearlmutter, 2004, p. 6) the two noun phrases (*bracelet* and *silver*) are semantically closely integrated since the phrase describes how the two nouns are related. In contrast, in the phrase *the ketchup or the mustard* (Solomon & Pearlmutter, 2004, p. 6) the two noun phrases (*ketchup* and *mustard*) are only loosely integrated because there is no information how the *ketchup* is related to the *mustard*. If the coordination of both items in a phrase were executed in parallel, handling two noun phrases that are more integrated with each other as two separate items should be more difficult and therefore prone to error than two noun phrases that are semantically less integrated with each other. In a serial account, on the other hand, the steps of word integration a sequenced and therefore, the semantic integration of the noun phrases should not affect their errors.

Solomon and Pearlmutter (2004) tested this, contrasting prepositional phrases with the preposition *of* or the preposition *with* between two noun phrases in (8). Solomon and Pearlmutter argued that the two noun phrases *drawing* and *flowers* in a prepositional phrase construction with *of* are more semantically integrated with each other than when they are connected with *with* in (8). The preposition *of* in Example (8a, 8b) describes and integrates the two nouns with each other to one unit, whereas *with* in Example (8c, 8d) merely describes that the nouns accompany each other. If the parallel activation-based account is correct, there should be more agreement errors for the plural prepositional phrase containing an *of* preposition.

8. (a) **tightly integrated / singular**
   The drawing of the flower

   (b) **tightly integrated / plural**
   The drawing of the flowers

   (c) **loosely integrated / singular**
   The drawing with the flower

(d) **loosely integrated / plural**
The drawing with the flowers
(Solomon & Pearlmutter, 2004, p. 9)

Solomon and Pearlmutter (2004) reported a main effect of number of the prepositional phrase: using plural local nouns (8b, 8d) resulted in more agreement errors than singular local nouns (8a, 8c). Most importantly, there was an interaction: there were more agreement errors in the plural conditions when the preposition was *of* in (8b) than when the preposition was *with* in (8d).

Thus, the findings of Solomon and Pearlmutter support the parallel activation-based account. They showed that the production of a prepositional phrase where the noun phrases are semantically more integrated cause more agreement errors and therefore more attraction. Solomon and Pearlmutter argued that these agreement errors are a consequence of the two noun phrases interfering with each other during the parallel phrase construction.

Bock, Eberhard, and Cutting (2004) and Eberhard, Cutting, and Bock (2005) proposed the marking and morphing model to account for attraction effects. Consider the phrase: *The largest of them is red* (Eberhard et al., 2005, p. 533), which contains a subject (*the largest*), a prepositional phrase (*of them*), a verb *is* and an adjective *red*. The subject *the largest* and the verb *is* have to agree in number. According to the *marking and morphing* mode, agreement starts by determining the number of the subject first. Verbs on their own do not carry number information and acquire their number from their subject. Thus, the number of the subject controls the number of the verb after the notional number of the subject noun is determined. The notional number of a noun is the conceptual number information of that noun, which does not actually have to coincide with the grammatical number of that noun. The *news*, for instance, might grammatically have a plural form, but it is perceived to be singular. Thus, the notional number of *news* is singular, while grammatically *news* is plural (Bock & Eberhard, 1993; Bock et al., 2004).

Once this notional number of the noun is determined, *marking* transmits the number information to the syntax of the sentence. Using the number information of the subject, syntactic processes subsequently set the number for those elements that have to agree with the number of the subject noun (e.g., verbs like *is* and pronouns). Afterwards, the number information is bound to structural positions (e.g., to positions that need the number information like the verb position) in the sentence and will be transmitted to the verb, this is the *morphing* process.

Eberhard et al. (2005) argued that agreement errors occur during the morphing process. When the number of the whole subject phrase needs to be established, the plural number feature can access this process, overwriting the number information of the phrase which results in an attraction error. In the example of a number attraction error *the key to the cabinets are on the table* from Bock and Miller (1991), the noun *cabinets*, which is not the subject of the phrase, sometimes specifies its own number as the number classification of the phrase (*(The key to the cabinets)$_{plural}$*). When the notional number of the head of the phrase is erroneously perceived to be plural, attraction errors occur and the following verb erroneously agrees with *the cabinets*.

The marking and morphing account claims that verbs themselves do not carry number, they receive their number information from the subject. Thus, how speakers perceive the number of the previous noun phrases should affect the form of the verb and therefore the occurrence of the number attraction effect.

Bock et al. (2004) tested predictions made by the marking and morphing model. In a first production experiment, Bock et al. tested the original materials from Bock and Miller (1991) in (9). In Example (9), a prepositional phrase with singular subjects (9a, 9b) were contrasted with plural subjects (9c, 9d). In addition, the subject complement noun (*cabinet*) was either singular (9a, 9c) or plural (9b, 9d).

9. (a) **singular / singular**
   The key to the cabinet
   (b) **singular / plural**
   The key to the cabinets

(c) **plural / singular**
The keys to the cabinet

(d) **plural / plural**
The keys to the cabinets
(Bock et al., 2004, p. 256)

Bock and Miller (1991) reported that the highest number of agreement errors occurred when the second noun phrase is plural and the subject noun is singular (9b).

The marking and morphing model claimed that the verb gets its number information from the subject. The occurrence of an agreement error depends on how speakers perceive the number information of the subject. In case of the notional number of a noun *team*, while singular, might be perceived as plural since it is a collective of several individual players. Therefore, the plural of a collective noun (*teams*) might be a stronger number attractor than the plural of an individual noun (*players*). To test this prediction Bock et al. (2004) conducted another production experiment where the local number attractor was either an individual noun *player(s)* in (10a, 10b) or a collective noun team(s) in (10c, 10d). Both collective and individual local nouns were either plural in (10b, 10d) or singular in (10a, 10c).

10. (a) **individual singular**
The record of the player

(b) **individual plural**
The record of the players

(c) **collective singular**
The record of the team

(d) **collective plural**
The record of the teams
(Bock et al., 2004, p. 262)

Bock et al. (2004) reported a main effect of number attraction: there were more agreement errors when the local noun phrase was plural than when the local noun phrase was singular. More interesting, there were even more agreement errors when the local number attractor was a collective noun (*teams*) in (10d) than when the local number attractor was an individual noun (*players*) in (10b). This finding supports the prediction made by the marking and morphing model which claimed that the notional number of the local attractor noun affects the occurrence of number agreement errors.

5.1.3 A memory retrieval account

Models in agreement research have argued that the attraction effect might be a consequence of either the syntactic structure (Franck et al., 2006), the parallel activation of noun phrases that are closely integrated with each other (Solomon & Pearlmutter, 2004), or the misguided morphing processes that control the agreement (Bock et al., 2004; Eberhard et al., 2005). Badecker and Kuminiak (2007), on the other hand, argued that the attraction effect might be caused by processes of memory retrieval. They argued that in order to establish the number information of the verb after the prepositional phrase, *The key to the cabinets*, the subject and its number information need to be accessed in memory. The model of Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) describes how retrieval cues are used to access an item in memory. Badecker and Kuminiak argued that attraction effects occur because the activation of the subject noun decays over time and therefore might be difficult to access. Thus, when the subject has become unavailable for the retrieval probe the intermediate noun phrase might be accessed instead. Erroneously taking the intervening items as the subject, the number of the to-be-produced verb will agree with the local plural noun.

An attraction effect in language production usually occurs when the local attracting noun is plural. The retrieval-cue based parsing account by (Van Dyke & Lewis, 2003) and Lewis and Vasishth (2005) claims that there are other retrieval cues besides number, e.g. there are retrieval cues for animacy and for gender. Observations about attraction errors in English have usually been limited to the inflection of number information. Other languages, like Slovak, have a richer inflection system than English and mark the gender information. Badecker and Kuminiak (2007) tested whether gender information, when openly marked, can induce an attraction effect. Slovak is a language that marks gender and the verb form has to agree with the gender of its subject noun. Badecker and Kuminiak claimed that if retrieval cues guide the access to the subject, a gender marked noun (In this context a noun is said to be gender marked when it is either masculine or feminine. Neuter, on the other hand, is not gender marked.) between a neutral subject and the main verb should induce attraction and the gender information of the verb will sometimes erroneously agree with the gender of the intervening noun.

Badecker and Kuminiak (2007) tested this prediction in a production study in Slovak. In Example (11a-11d), the masculine marked noun *pohár*$_M$ is compared with a gender neuter noun *okno*: in the prepositional phrase, the subject noun was either masculine (11a, 11b) or neuter (11c, 11d). They were presented with a local noun that was either masculine (11a, 11c) or neuter (11b, 11d). In addition to the masculine vs. neuter comparison Badecker and Kuminiak contrasted masculine marked gender nouns with feminine marked gender nouns in prepositional phrases in (11e-11h). The subject head noun was either feminine (11e,11f) or masculine (11g, 11h), while the local attractor noun was also either masculine (11f, 11g) or feminine (11e, 11h). Badecker and Kuminiak argued that a gender marked attractor noun (a gender marked noun is either feminine or masculine) should cause more agreement errors at the following verb than a gender neuter attractor noun. Therefore, conditions that have a gender marked attractor noun (11d, 11f, 11h) should elicit more agreement errors than the conditions that either have a neuter attractor noun (11b) or whose gender information matches between the two noun phrases (11a, 11c, 11e, 11g).

11. (a) **masculine / masculine**
    Pohár$_M$ na čai$_M$
    The glass for tea

    (b) **masculine / neuter**
    Pohár$_M$ na mlieko$_N$

The glass for milk

(c) **neuter / neuter**
Okno$_N$ na pole$_N$
The window to the field

(d) **neuter / masculine**
Okno$_N$ na dvor$_M$
The window to the yard

(e) **feminine / feminine**
Baňa$_F$ na med'$_F$
The mine for copper

(f) **feminine / masculine**
Baňa$_F$ na nikel$_F$
The mine for nickel

(g) **masculine / masculine**
Spor$_M$ o klenot$_M$
The quarrel over the jewel

(h) **masculine / feminine**
Spor$_M$ o korist'$_F$
The quarrel over the loot
(Badecker & Kuminiak, 2007, p. 71)

Badecker and Kuminiak reported that the masculine attractor (11d) caused more agreement errors at the verb than the neuter attractor (11b). In addition, the feminine attractors (11h) caused more attraction than the masculine attractor. The masculine-neuter and the feminine-masculine settings caused a small amount of attraction errors on the verb. These findings are in agreement with the predictions made by the memory retrieval account of Van Dyke and Lewis (2003) which described how retrieval cues for e.g. number, case and gender affect language processing. However, it is interesting to note that while the masculine-feminine setting caused agreement errors, the feminine-masculine setting did cause only little attraction. Both, feminine and masculine nouns are gender marked in contrast to neuter nouns, though

Badecker and Kuminiak argued that femininity might be a stronger mark for gender than masculinity.

However, Experiment 1 was not completely counterbalanced: the feminine gender marking noun was never compared with a neuter noun in the prepositional phrase. In another production experiment Badecker and Kuminiak tested prepositional phrases with a neuter subject and a neuter attractor (12a), a masculine attractor (12b) and a feminine attractor. If the feminine noun is stronger gender-marked, it should elicit more agreement errors than the masculine local attractor when the subject noun is neuter.

12. (a) **neuter / neuter**
    Múzeum$_N$ pre okolie$_N$
    (The museum for the locale)

    (b) **neuter / masculine**
    Múzeum$_N$ pre okres$_M$
    (The museum for the county)

    (c) **neuter / feminine**
    Múzeum$_N$ pre obec$_F$
    (The museum for the village)
    (Badecker & Kuminiak, 2007, p. 78)

Badecker and Kuminiak (2007) reported agreement errors when the local noun is marked with the masculine (12b) or the feminine gender (12c). The difference between the amount of agreement errors of the feminine and the masculine attractor was not significant.

Thus both a feminine and a masculine noun phrase attract gender information when there is a neuter subject noun. However the findings of the previous experiment suggested that in comparison with each other, a feminine noun phrase seems to be a stronger attractor when it is preceded by a masculine subject than a masculine noun phrase when it is preceded by a feminine subject.

Badecker and Kuminiak (2007) concluded that these findings are best explained by the memory retrieval account by Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) that described gender as one of the retrieval cues.

5.2 Attraction in comprehension

The previous studies have shown how number information of a local noun might erroneously misinform verb agreement processes and result in the production of a verb whose number marking agrees with the local plural noun instead with the singular subject noun. It has been shown that these agreement errors occur more often when the subject noun of a prepositional phrase is singular and the local noun phrase is plural than when the subject is plural and the local noun phrase is singular. This observation also known as mismatch asymmetry might be an indicator that a plural noun phrase is more marked than a singular noun phrase. Thus, a plural local noun in a prepositional phrase is a stronger number attractor than a singular local noun in a prepositional phrase. While these processes have been thoroughly investigated in production, the extent to which they affect comprehension processes remains unclear. The next section will introduce research that shows number attraction effects in comprehension.

5.2.1 Evidence for number attraction in comprehension

The previous chapters have described effects of attraction errors in language production studies (Bock & Miller, 1991; Bock & Cutting, 1992; Bock et al., 2004; Franck et al., 2006; Badecker & Kuminiak, 2007). Nicol, Forster, and Veres (1997) argued that the identification of agreement features are part of the computation of syntactic structures and these agreement processes underly comprehension and production processes alike. In case processes of agreement can generally be violated then effects of number attraction should also affect processes of comprehension. Nicol et al. (1997) tested these predictions in comprehension using offline sentence classification tasks (a string of words appear on the screen and participants were asked to judge whether this string appeared in the proper order). In Example (13) Nicol et al. (1997) contrasted sentences with an initial prepositional phrase: the subject (*author(s)* in 13) was either followed by a singular attractor (*speech* in 13a, 13d) or a plural attractor (*speeches* in 13b, 13c). In addition, the number of the subject of the prepositional phrase was either singular (*author* in 13a, 13b) or plural (*authors* in 13c, 13d). When agreement processes are subject to violation from noun phrases that are number marked (Eberhard, 1997) then, according to Nicol et al. (1997), this should affect the comprehension (13b). The prepositional phrase in (13b) has an unmarked singular subject (*author*) and a marked plural attractor (speeches) preceding the verb (*was*). In case, the number feature from the plural number attractor does indeed migrate during number agreement processes, this should affect the reading of the verb (*was*).

13. (a) **singular subject / singular attractor**
    The author of the speech was subsequently well rewarded.

    (b) **singular subject / plural attractor**
    The author of the speeches was subsequently well rewarded.

    (c) **plural subject / plural attractor**
    The authors of the speeches were subsequently well rewarded.

    (d) **plural subject / singular attractor**
    The authors of the speech were subsequently well rewarded.
    (Nicol et al., 1997, p. 577)

Nicol et al. (1997) reported interactions in the response times and the error rates about the judged sentences. For sentences with a singular subject in the prepositional phrase, those with a plural number attractor (13b) had longer reaction times and a higher error rate than those with a singular number attractor after a singular subject (13a). There was no significant difference between the two conditions (singular and plural number attractor) with the plural subjects of the prepositional phrase. These findings are in agreement with the predictions made by Nicol et al. (1997) and support the notion that number attraction affects processes of comprehension.

In another experiment, Nicol et al. (1997) tested whether it is indeed processes of number agreement that cause number attraction effects. Nicol et al. (1997) compared similar constructions to those used in (13). There is one crucial difference, in Example (14) the verb (*will*) following the number attractor (*speech(es)*) was not number number marked. Without number marking at the verb, no number agreement processes should affect the comprehension.

14. (a) **singular subject / singular attractor**
    The author of the speech will be well rewarded.

    (b) **singular subject / plural attractor**
    The author of the speeches will be well rewarded.

    (c) **plural subject / plural attractor**
    The authors of the speeches will be well rewarded.

    (d) **plural subject / singular attractor**
    The authors of the speech will be well rewarded.
    (Nicol et al., 1997, p. 579)

In agreement with the predictions, Nicol et al. (1997) reported no main and no interaction effects in the reaction times and in the error rates. Thus, this suggests that there are no effects of number agreement when the verb is not number marked.

In another offline sentence judgement experiment Nicol et al. (1997) investigated whether an embedded number attractor can affect comprehension processes. Production research (Bock & Cutting, 1992) suggested that a number attractor that is embedded in a relative clause is less likely to cause an attraction error at the following verb. In (15) Nicol et al. (1997) contrasted number attractors (*realtor(s)*) that were embedded in a relative clause that directly related to the head subject (*owner* in 15a, 15b) with relative clauses that did not directly relate to the head subject (*owner* in 15c, 15d). Overall, Nicol et al. (1997) predicted that if there was an effect of the embedded number attractor (*realtors*), this should occur in the condition when the number attractor is in the relative clause that relates to the head subject (*owner*). The number attractor in the direct relative clause condition (15a, 15b) can directly override the unmarked number of the subject. Whereas it is unclear which noun phrase the relative clause is referring to in the indirect relative clause condition (15c, 15d).

15. (a) **direct relative clause / singular attractor**
    The owner of the house who charmed the realtor was no longer willing to sell.
    (b) **direct relative clause / plural attractor**
    The owner of the house who charmed the realtors was no longer willing to sell.
    (c) **indirect relative clause / singular attractor**
    The owner of the house which charmed the realtor was no longer willing to sell.
    (d) **indirect relative clause / plural attractor**
    The owner of the house which charmed the realtors was no longer willing to sell.
    (Nicol et al., 1997, p. 583)

Nicol et al. (1997) reported an interaction: for the direct relative clause conditions, those conditions with a plural number attractor (15b) had longer reaction times than those with a singular number attractor (15a). There was no difference in the reaction times for the two indirect relative clause conditions (15c, 15d). These findings are in agreement with the predictions made by Nicol et al. (1997), there was a number attraction effect in the direct relative clause. However, these findings are at odds with those from production research that reported fewer attraction errors when the number attractor was embedded in a relative clause. However, the dependent measures in these comprehension experiments were reaction times after reading the sentence and error rates of grammaticality judgements. These offline measures might be a poor reflection of online comprehension processes.

Nicol et al. (1997) presented comprehension experiments showing that number attraction can affect sentence comprehension. Overall, their findings are similar to the findings reported in production studies. However, they report number attraction effects from an embedded plural number attractor whereas studies of production have shown fewer attraction errors from an embedded number attractor.

5.2.2 How does number attraction affect online reading times?

Effects of number attraction on a verb directly following a local plural noun have been commonly observed in language production. However, does number attraction also affect comprehension processes? Pearlmutter, Garnsey, and Bock (1999) presented online reading experiments that explored number attraction effects in comprehension using eye-tracking and the self-paced reading paradigm.

The sentences in (16) contained a prepositional phrase which was followed by either a singular verb phrase (*was* in 16a and 16b) or a plural verb phrase (*were* in 16c and 16d). The sentence subject (*key*) was singular in all conditions which makes the sentences with a plural main verb ungrammatical and those with a singular main verb grammatical. Furthermore, the number of the noun before the verb was either singular (16a,16c) or plural (16b,16d). If attraction indeed affects comprehension processes, then it should affect the reading of the verb (*was*) in the grammatical condition when it is preceded by a plural number attractor noun (*cabinets*) in (16b). Number attraction should also affect the reading times of the verb (*were*) in the ungrammatical condition (16d).

16. (a) **grammatical: singular / singular**
    The key to the cabinet was rusty from many years of disuse.

    (b) **grammatical: singular / plural**
    The key to the cabinets was rusty from many years of disuse.

    (c) **ungrammatical: singular / singular**
    * The key to the cabinet were rusty from many years of disuse.

    (d) **ungrammatical: singular / plural**
    * The key to the cabinets were rusty from many years of disuse.
    (Pearlmutter et al., 1999, p. 432)

The reading times of the self-paced reading experiment in Pearlmutter et al. (1999) showed a main effect of number mismatch at the verb (*was/were*). The conditions with mismatching noun phrases (16b,16d) were read slower than the conditions with matching noun phrases (16a,16c). At the region following the verb (*rusty*) an effect of grammaticality was observed with the grammatical conditions (16a,16b) being read faster than the ungrammatical conditions (16c,16d). Interestingly, Pearlmutter et al. (1999) reported an interaction effect at *rusty*: the grammatical condition with the singular local noun (16a) had shorter reading times than the grammatical condition with the plural local noun (16b). The difference between the ungrammatical conditions that either had a local singular noun (16c) or a local plural noun (16d) was not significant.

For the eye-tracking experiment Pearlmutter et al. (1999) reported that the grammatical conditions (16a,16b) were read faster than the ungrammatical conditions in (16c, 16d) in total reading time and first-pass time. More importantly, there were interactions at the verb region (*was rusty*) in first-pass reading and in first-pass regression. The grammatical conditions with matching noun phrases (16a) had shorter first-pass reading times than the grammatical conditions with mismatching noun phrases (16b), while the reading times between the two ungrammatical conditions (16c,16d) was not significantly different. There were also more regressive saccades from the verb *was* in the ungrammatical condition when the local noun phrase was singular (16c) than when the local noun was plural (16d). The difference between the grammatical conditions (16a,16b) was not significant.

Thus, both eye-tracking and self-paced experiments in Pearlmutter et al. (1999) showed that the ungrammatical sentences were more difficult than the grammatical sentences. The interactions in both experiments showed that number attraction could affect comprehension processes. In the self-paced reading experiment, a local number attractor increased the reading times of the grammatical sentences. In the eye-tracking experiment, the presence of a local number attractor made the ungrammatical conditions less difficult than when there was a singular local noun.

The approach by Pearlmutter et al. (1999) to use online reading paradigms like self-paced reading and eye-tracking are advantageous to the methodologies used in previous studies. Research studies investigating number agreement violations in comprehension are usually accompanied by some subsidiary tasks (e. g., grammaticality judgement tasks in Nicol et al. (1997) or lexical decision tasks like in Jakubowicz and Faussart (1995)).

Pearlmutter et al. (1999) argued that a secondary task like grammaticality judgement in Nicol et al. (1997) might increase sensitivity of the readers towards the critical number marking of the noun phrases in the sentence. In addition, those tasks (especially the lexical decision tasks and the grammaticality judgements) increased the reading times of the sentence, which suggest that these exercises might add an artefact to normal reading.

Pearlmutter et al. (1999) presented ungrammatical sentences for participants to read. The interpretation of the reading times of ungrammatical sentences is challenging since they may not reflect the same processes that occur during the reading of grammatical sentences. Thus, the findings of the self-paced experiment showed effects of number attraction. However, eye-tracking data can reflect a more natural reading behaviour while in addition also providing more reading time measures. The eye-tracking data in Pearlmutter et al. (1999) however did not show that number attraction affected the reading of grammatical sentences. They also showed that number attraction affected the reading of ungrammatical sentences.

5.2.3 An account of hierarchical feature processing

In production research, Pearlmutter (2000) described a *hierarchical feature-passing system* that accounts for number agreement errors. According to this account, number information will be passed between adjoining branches in a *hierarchical tree structure*. Feature information will be passed between nodes of the hierarchical tree structure upwards up to the maximal projection. This process is also referred to as percolation of the number information.

A mistake in the number percolation process would cause an agreement error in production. Thus, the number feature of the modifier *cabinets* would erroneously overwrite the number feature of its projection *key* in (17). As a result of this overwriting process of *key* as *keys* the produced verb *were* would agree with the new subject. Pearlmutter (2000) argued that the hierarchical feature passing account applies to processes in production and comprehension.

17. **ungrammatical**
    * The key to the cabinets were rusty from many years of disuse.
    (Pearlmutter et al., 1999, p. 432)

According to Pearlmutter (2000) the hierarchical feature-passing account predicted that attraction is strongest from a noun phrase that is higher in the hierarchical tree structure, while the linear feature tracking account predicted that attraction will be caused by the more recent noun phrase. According to the linear account, at the verb (*were* in 17) the stored number information of the subject head will be matched against the number information of the verb and this predicts recency effects. Similar to other information that is held by a working memory system, the memorised number information of the subject is susceptible to decay over time (Stevenson, 1994).

In order to differentiate between a hierarchical and a linear feature tracking system Pearlmutter (2000) described two comprehension experiments using self-paced reading.

The materials used by Pearlmutter (2000) contained a prepositional phrase with three nouns. In the materials below there are three nouns before the main verb. *The lamp* is the first and the subject head noun in singular, the second *the painting* modifies the head noun and the third *the house* modifies the second noun phrase. The second noun phrase (*painting(s)*) was either singular in (18a,18b) or plural in (18c,18d). In addition, Pearlmutter manipulated the number of the third noun phrase (*house(s)*), which was either singular in (18a, 18c) or plural in (18b, 18d).

The hierarchical feature-passing and the linear feature tracking account make different predictions about agreement effects. A hierarchical feature tracking account claims that the number feature percolates upwards and therefore the noun phrase that is higher in the hierarchical structure is more likely to cause an attraction effect. Therefore, according to the hierarchical feature tracking account, the number of the second noun phrase should affect the reading times at the verb (*was*). The linear feature tracking account, on the other hand, predicts that because the number information of the second noun phrase had more time to decay it does not affect the reading time of the verb. The number information of the third noun phrase (*houses* in 18b and 18c) can have an adverse effect at the reading time of the verb (*was*), since it immediately precedes the verb (*was*).

18. (a) **singular / singular**
    The lamp near the painting of the house was damaged in the flood.

    (b) **singular / plural**
    The lamp near the painting of the houses was damaged in the flood.

    (c) **plural / singular**
    The lamp near the paintings of the house was damaged in the flood.

    (d) **plural / plural**
    The lamp near the paintings of the houses was damaged in the flood.
    (Pearlmutter, 2000, p. 5)

Reading times for the first experiment in Pearlmutter (2000) showed no main effects. However, Pearlmutter (2000) reported an interaction, the condition with all singular noun phrases was read faster than all other conditions. These findings are not in agreement with either the hierarchical nor the linear feature tracking account. Pearlmutter (2000) argued that the singular head noun since it was unmarked might have been interfered by the plural second and or plural third noun phrase. However, this interference might have been too weak. In a second experiment, Pearlmutter (2000) used similar materials though with plural head nouns in (19). Plural head nouns are marked and therefore are less likely to be interfered by the second and the third following noun phrase.

19. (a) **singular / singular**
    The lamps near the painting of the house were damaged in the flood.

    (b) **singular / plural**
    The lamps near the painting of the houses were damaged in the flood.

    (c) **plural / singular**
    The lamps near the paintings of the house were damaged in the flood.

    (d) **plural / plural**
    The lamps near the paintings of the houses were damaged in the flood.
    (Pearlmutter, 2000, p. 7)

Pearlmutter (2000) reported that there were longer reading times at the verb when the second noun phrase was singular (19a,19b) than when the second noun phrase was plural (19c,19d). The number of the third noun phrase had no effect on the reading times at the verb.

These findings are more in agreement with the hierarchical feature passing than with the linear feature tracking account. The hierarchical model predicted that the number feature of the second noun phrase (*painting(s)*) is more likely to affect reading times since it is higher in the syntactic hierarchy. The linear feature tracking account, on the other hand, is challenged by these results. The linear account originally predicted an effect of the third noun phrase (*house(s)*), which was not observed.

Pearlmutter (2000) concluded that number information is passed between adjoining nodes in a hierarchically structured phrase structure tree. Plural noun phrases are stronger number marked than singular noun phrases and if the plural number feature erroneously overrides a singular number feature, this mistake will result in a number attraction effect at the verb.

5.2.4 Number agreement errors in comprehension

The studies of Pearlmutter et al. (1999) and Pearlmutter (2000) have shown that number attraction can also affect comprehension processes. The findings in Pearlmutter et al. suggested that the local plural noun of a prepositional phrase can cause longer reading times at the following singular verb in grammatical sentences. Pearlmutter (2000) then showed that the disruption associated with an interfering mismatching noun phrase is more likely when a number attractor is syntactically closer to the head noun than when the number attractor is directly preceding the verb.

Pearlmutter (2000) described a hierarchical feature passing process in order to account for the number attraction effect in comprehension. According to this, when agreement processes fail, the number feature of the head will be replaced by the number feature of the adjacent node noun. Wagers et al. (2009) however argued that agreement is not the result of an incorrect subject representation, but comprehension is guided by the same retrieval cue processes that also cause similarity based interference effects.

In order to test this, Wagers et al. (2009) conducted a self-paced reading experiment. Sentences containing object relative clauses were tested in (20) where the sentence subject (*musician(s)*) was either plural (20aii, 20aiv) or singular (20ai, 20aiii). The embedded subject of the relative clause (*reviewer*) was singular in (20a). However, the embedded verb (*praise(s)*) that should agree with the embedded subject was either in singular or in plural. Thus, a singular verb (*praises*) was presented in the grammatical conditions (20ai, 20aii), whereas the plural verb (*praise*) rendered the sentences (20aiii, 20aiv) ungrammatical.

In case the feature passing account by Pearlmutter (2000) holds, there should only be an effect of grammaticality at the verb *praises*. There should be no attraction effect since the number attractor (*musicians*) is not between the embedded subject and the verb and therefore the number information should not percolate. The retrieval cue parsing account on the other hand predicted an attraction effect at the embedded verb *praise(s)*. When the verb *praise(s)* needs to be integrated with its dependents (*musician(s)* and *reviewer*), the number cue guides the retrieval process. Interference will occur when the retrieval probe fails to identify the target (*musician*) because there is another noun phrase in memory (*reviewer*) that is also, like the target, singular. Since comprehension is guided by retrieval cues, the number cue of the nouns guides the integration of *praise(s)*.

20. (a) **singular subject**

    i. **singular attractor / grammatical**
    The musician who the reviewer praises so highly will probably win a Grammy.

    ii. **plural attractor / grammatical**
    The musicians who the reviewer praises so highly will probably win a Grammy.

    iii. **singular attractor / ungrammatical**
    The musician who the reviewer praise so highly will probably win a Grammy.

    iv. **plural attractor / ungrammatical**
    The musicians who the reviewer praise so highly will probably win a Grammy.

    (b) **plural subject**

    i. **singular attractor / grammatical**
    The musician who the reviewers praise so highly will probably win a Grammy.

    ii. **plural attractor / grammatical**
    The musicians who the reviewers praise so highly will probably win a Grammy.

    iii. **singular attractor / ungrammatical**
    The musician who the reviewers praises so highly will probably win a Grammy.

    iv. **plural attractor / ungrammatical**
    The musicians who the reviewers praises so highly will probably win a Grammy.

(Wagers et al., 2009, p. 213)

Wagers et al. (2009) reported an interaction between grammaticality and the number of the embedded subject noun. This interaction was observed at the spillover region *so*, which directly followed the critical verb (*praise(s)*). A pairwise comparison showed that the ungrammatical condition with a singular attractor (20aiii) had longer reading times than the ungrammatical condition with the plural attractor (20aiv). The comparison of the two grammatical conditions (the one with a singular attractor and the other with a plural attractor) did not show any significant differences. Wagers et al. concluded that the head noun of a relative clause can cause attraction effects during the comprehension of ungrammatical sentences.

The majority of the productions studies, however, reported the occurrence of agreement errors for prepositional phrase constructions and only a small amount of agreement errors for relative clauses. Pearlmutter et al. (1999) already presented findings of attraction effects in comprehension using prepositional phrases. However, Wagers et al. (2009) argued that the observed attraction effects at the verb might actually be effects of spillover. The local noun (*cabinet(s)*) causing an attraction effect directly precedes the verb (*was*) in (21). If the difficulty associated with the processing of the plural spills over to the verb, the observed slow-down for (21b) at the verb is not an attraction but rather a spillover effect (Vasishth, 2006).

21. (a) **local singular noun**
    The key to the cabinet was on the table.

    (b) **local plural noun**
    The key to the cabinets was on the table.

In order to avoid a potential spillover effect at the verb, Wagers et al. (2009) placed an adverb like *unsurprisingly* between the local noun (*cell(s)*) and the main verb (*was / were*) of the sentence in (22). If the difficulty of processing a plural in contrast to a singular noun phrase indeed spilled over to the following word, it would occur at *unsurprisingly* and the effect found at the verb *was / were* would be due to with the plural number of the local noun *cells*.

22. (a) **singular attractor / grammatical**
    The key to the cell (unsurprisingly) was rusty from many years of disuse.

    (b) **plural attractor / grammatical**
    The key to the cells (unsurprisingly) was rusty from many years of disuse.

    (c) **singular attractor / ungrammatical**
    The key to the cell (unsurprisingly) were rusty from many years of disuse.

    (d) **plural attractor / ungrammatical**
    The key to the cells (unsurprisingly) were rusty from many years of disuse.
    (Wagers et al., 2009, p. 221)

The reading times of this self-paced reading study supported the findings of the relative clause study. Wagers et al. (2009) reported an interaction showing that in the ungrammatical conditions a singular attractor had longer reading times than a plural attractor at the region after the verb (*rusty*). Thus, the difficulty associated with the ungrammatical conditions is reduced when the local noun is plural. Interestingly, the reading times did not show an attraction effect for the grammatical conditions as was originally reported by Pearlmutter et al. (1999). Wagers et al. argued that the findings of Pearlmutter et al. of number attraction during the comprehension of grammatical sentences might actually have been due to spillover effects.

Thus, Wagers et al. (2009) found effects of number attraction in comprehension. However, these effects only occurred in ungrammatical sentences and did not affect the processing of grammatical sentences. This finding is difficult to reconcile with the feature percolation account. According to percolation, the number feature of the local plural noun should spread to the head noun and therefore should affect the reading times of grammatical and ungrammatical alike.

The findings of Wagers et al. (2009) that number attraction affects the comprehension of ungrammatical sentences is similar to the results presented by Kaan (2002). Using ERPs and grammatical judgement measures, Kaan investigated number attraction effects in Dutch in grammatical and ungrammatical sentences. While the behavioural data and the positivity showed effects of grammaticality (ungrammatical sentences were judged less correctly and were more negative in the ERPs), the effects of number attraction was less clear. The ERP showed that a singular subject with an interfering object resulted in a reduced positivity of the ungrammatical conditions in comparison to the grammatical conditions at around 250ms. In all other number information conditions (singular subject-singular object, plural subject-singular object and plural subject-plural object) at 250ms there was no difference between the grammatical and the ungrammatical conditions. Thus, Kaan showed that number attraction can affect the processing of ungrammatical sentences. However, the interpretation of reading times of ungrammatical sentences is difficult since the processing of ungrammatical sentences is different to the processing of grammatical sentences.

Wagers et al. (2009) discussed how a content-addressable memory system that uses retrieval cues (Van Dyke & Lewis, 2003; Lewis & Vasishth, 2005) might be able to account for these results. For normal agreement processes in grammatical sentences, retrieval cues can be used to search for the subject in memory. In the ungrammatical sentences, this search would be unsuccessful and might trigger a reanalysis process, therefore taking longer. Thus, Wagers et al. concluded that the effects might be best explained by the retrieval cue based parsing account since it can account for the different findings of the grammatical and the ungrammatical sentences.

6 Experiment 3

Number attraction has been shown to affect sentence comprehension (Pearlmutter et al., 1999; Pearlmutter, 2000; Kaan, 2002; Wagers et al., 2009). However, the findings of Wagers et al. (2009) indicate that the number attraction effect reported by Pearlmutter et al. (1999) might actually have been a spillover effect. Pearlmutter et al. reported longer reading times at the verb after a plural noun and suggested this might be due to number attraction. However, this increase in reading times might originally have been caused by the previous plural noun (plural nouns are longer and might therefore be more difficult) and this difficulty might have spilled over onto the verb. In addition, Kaan (2002) and Wagers et al. (2009) reported effects of number attraction that were confined to ungrammatical sentences. The findings of Pearlmutter (2000) are not very clear, they showed number attraction effects from an interfering singular noun phrase in comprehension instead of an interfering plural noun phrase. According to the production literature, number attraction errors are most likely to occur when the local interfering noun phrase is plural, therefore it is unclear why there is a number attraction effect from an interfering singular noun phrase in Pearlmutter (2000).

Thus, there are currently no clear findings that suggest that number attraction indeed affects the processing of grammatical sentences.

There might be various reasons why clear effects could not have been observed. For example, Wagers et al. (2009) reported effects of number attraction for ungrammatical sentences. However, the interpretation of how people process ungrammatical sentences is challenging since there might be other processes involved than in the processing of grammatical sentences. In case readers encounter an item that cannot be grammatically integrated into the sentence structure build so far, they might make more regressive eye movements to find a potential location in the sentence that has been misinterpreted. Once readers failed to process the sentence, they might give up completely and abandon the sentence processing task. Thus, it is challenging to compare the processing of grammatical with the processing of ungrammatical sentences.

For the study of Wagers et al. (2009) this means that the effect of number attraction might be weak and in addition to that other effects might be stronger and override effects of number attraction during comprehension. There are various accounts for the processing of grammatical sentences. For instance, similarity interference due to retrieval cue overlap makes different predictions about processing difficulty than the number attraction account. Curiously, Badecker and Kuminiak (2007) as well as Wagers et al. (2009) actually explained the number agreement attraction effect as a memory effect that involved retrieval cues. An account of retrieval interference due to retrieval cue overlap predicts conditions with two singular noun phrases to be more difficult than conditions with a singular and a plural noun phrase. The retrieval probe should have more difficulty finding the target *chauffeur* in (1) when there are interfering items in memory that match the retrieval cues of the retrieval probe such as *assistant* and *politician* (Van Dyke & Lewis, 2003; Lewis & Vasishth, 2005; Van Dyke, 2007). There should be more interference from NP3 (*politician(s)*) than NP2 (*assistant(s)*). The interference account predicts that the activation of NP2 (*assistant(s)*) should have decayed and therefore this noun phrase is less likely to cause an interference effect at the position of the verb *was*. Whereas, the NP3 *politician(s)* directly precedes the verb *was* and since the activation of NP3 has less time to decay, NP3 is most likely to interfere at the position of the verb *was*.

The number attraction account, on the other hand, predicts difficulty when the singular verb is preceded by a plural noun phrase (either the immediately preceding *politicians* or more distant *assistants* in (1)) for comprehension. There should be more attraction from NP2 (*assistant(s)*) than from NP3 (*politician(s)*) since NP2 is higher in the hierarchical structure and therefore more likely to c-command the following verb (see the discussion of the Franck et al. (2002, 2006) for a more detail).

These predictions were tested in eye-tracking Experiment 3. In Example (1), sentences contained a subject relative clause with a complex noun phrase (*the assistant of the politician*). Both nouns of the complex noun phrase varied in number: the subject was either singular (*assistant* in 1c,1d) or plural (*assistants* in 1a, 1b) and the second noun phrase was also either singular (*politician* in 1b, 1d) or plural (*politicians* 1a,1c). Solomon and Pearlmutter (2004) have argued that two noun phrases are semantically more integrated when they are connected with the preposition *of* instead of the preposition *with*. This semantic integration has been shown to induce more attraction errors, therefore the preposition *of* was used in (1) to integrate the two noun phrases with each other and therefore to increase the chance of finding an attraction effect.

1. (a) **plural NP2 / plural NP3**
   The chauffeur who greeted the assistants of the politicians was at the station's taxi rank.

   (b) **plural NP2 / singular NP3**
   The chauffeur who greeted the assistants of the politician was at the station's taxi rank.

   (c) **singular NP2 / plural NP3**
   The chauffeur who greeted the assistant of the politicians was at the station's taxi rank.

   (d) **singular NP2 / singular NP3**
   The chauffeur who greeted the assistant of the politician was at the station's taxi rank.

The findings in Experiments 1 and 2 showed only a weak effect of number interference. One reason might be that number interference is generally only a weak effect. An alternative explanation is that in the object-relative clauses used in Experiment 1 and 2, there was only one interfering item in memory in addition to the target item. Accounts of memory interference like Lewis (1996) claim that interference should only occur when there are at least two items interfering with memory processes. Therefore, if it is number interference, it should be a strong effect, since two interfering noun phrases were used in addition to the target noun. In comparison, Experiments 1 and 2 had only one interfering noun.

Therefore, accounts of number attraction and number interference make the following predictions about the observed reading times for sentences like (1). Interference predicts for Experiment 3 that conditions with interfering singular noun phrases in memory should be more difficult at the verb *was at* than the conditions with interfering plural noun phrases in memory. In contrast, number attraction predicts conditions with a plural noun preceding the verb to be more difficult than the conditions with a singular noun preceding the verb.

6.1 Method

6.1.1 Participants

Forty undergraduate students from the University of Dundee participated in this eye tracking experiment for course credit. All were non-dyslexic English native speakers with normal or corrected to normal vision.

6.1.2 Materials

Forty critical sentences were used in Experiment 3. The example (2) below shows a sample sentence in the four conditions. Each of these sentences contained an embedded subject relative clause while the sentence subject is always singular. A complex noun phrase consisting of two nouns served as the object in the relative clause (`assistant(s) of the politician(s)`). The main verb in this sentence was in present tense and overtly marked to agree with the sentence subject. The noun phrases in the relative clause were either in singular or in plural. The experiment had a 2×2 design. One factor in this experiment was the number of NP3. The noun phrase (*politician(s)*) closest to the main verb (*was*) is called NP3 and was either in singular (same number as the main verb) or in plural (different number from the main verb). As a second factor the number of the middle noun phrase NP2 (*assistant(s)*) was also either in singular (same number as the verb) or in plural (different number from the verb).

2. (a) **plural NP2 / plural NP3**
   The chauffeur who greeted the assistants of the politicians was at the station's taxi rank.

   (b) **plural NP2 / singular NP3**
   The chauffeur who greeted the assistants of the politician was at the station's taxi rank.

Table 20: Areas of interest for Experiment 3

critical	**spillover**	**final**
was at	the station's	taxi rank.

(c) **singular NP2 / plural NP3**
The chauffeur who greeted the assistant of the politicians was at the station's taxi rank.

(d) **singular NP2 / singular NP3**
The chauffeur who greeted the assistant of the politician was at the station's taxi rank.

Each experimental item was divided into different regions of interest. Table 20 shows these different interest area using the example sentence. The critical, the spillover and the final region were at least seven characters long. If the seventh character fell within a word the whole word would be assigned to the current interest area and the next word will be in the next interest area. The critical region contained the main verb *was* of the sentence and the following preposition *at*. The reading times at the critical region should show the effect of the manipulation of the preceding noun phrases NP2 and NP3. The spillover region is the region following the critical region. In case either the interference or the attraction effects are delayed, they should be observed at the spillover region (*the station's*). The spillover region was followed by the final region *taxi rank*. Late sentence wrap-up processes are expected to be observed at the final region.

In addition to the critical sentences, 65 filler sentences were presented. Each sentence was followed by a comprehension question. These question asked for different information in the critical sentences, 50% could be answered with Yes and 50% with No.

Table 21 shows the different types of comprehension questions using one sample sentence. The structure of the material allowed for two different kinds of Yes- and No-comprehension questions. They were used to ensure that participants read and attempted to understand the whole sentences as carefully as possible. The first Yes- and one No-question asked about the main clause, the other Yes and No question asked about the relation between main and relative clause.

Table 21: Comprehension questions - Experiment 3

The chauffeur who greeted the assistants of the politicians was at the station's taxi rank.

Yes - question	**No - question**
(a) Was the chauffeur at the station's taxi rank?	(a) Was the politician at the station's taxi rank?
(b) Did the chauffeur greet the assistants?	(b) Did the politicians greet the assistants?

6.1.3 Design

Experiment 3 had a 2×2 within-subjects design. One factor was the number feature of the local noun *the politicians*, which was either presented in plural or in singular. The second factor was the number marking of the second noun phrase *the assistant*, which was also either in singular or in plural.

Forty different critical sentences were created for the materials in Experiment 3. These were, like in previous experiments, distributed over four lists. Each list contained 40 critical sentences with five items in each of the four conditions. One condition of each item appeared in each list. Five participants were randomly assigned to each list. In addition to the critical 40 sentences, 105 filler sentences were presented and yes/no comprehension questions were presented after each sentence.

6.1.4 Apparatus and procedure

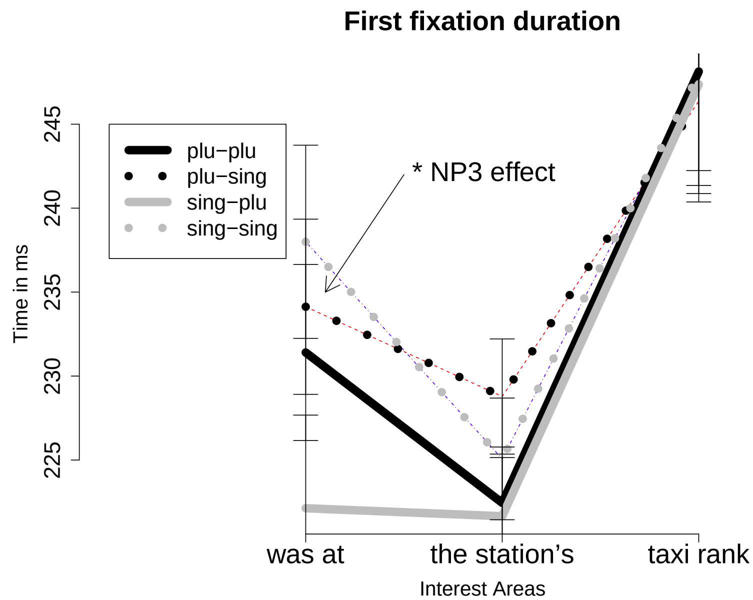
The same apparatus and procedure from Experiments 1 and 2 were used in Experiment 3.

6.2 Results

For Experiment 3, first fixation duration, first-pass time, regression-path time and total reading times were analysed. These measures were defined in the results section for Experiment 1.

Figures 11, 12, 13 and 14 illustrate the reading time measures (first fixation duration, first-pass time, regression-path time and total reading time respectively) on the different areas of interest (critical: *was at*, spillover: *the station's* and the final region: *taxi rank*. Table 26 shows the means of the comprehension question errors.

Tables 22 (first fixation duration), 23 (first-pass time), 24 (regression-path time), 25 (total reading time) and 27 (comprehension question error) show the p- and F-values for the by-subject and by-items analyses of Experiment 3.



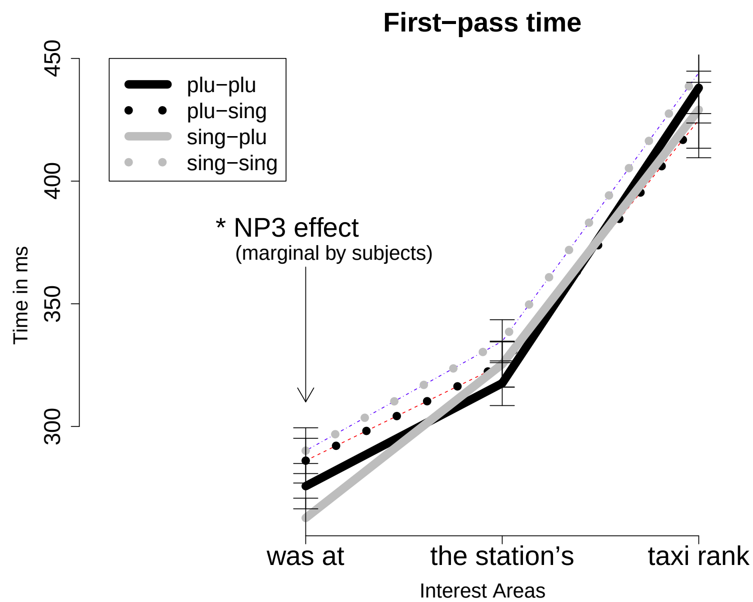
was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	critical	spillover	final
plural/plural	231.41	222.45	248.14
plural/singular	234.13	228.78	246.38
singular/plural	222.13	221.65	247.38
singular/singular	238.00	225.07	247.96

Figure 11: First fixation duration in ms - Experiment 3

Table 22: F and p values for first fixation duration - Experiment 3

F1/F2	critical	spillover	final
number of NP2			
F1	<1	<1	<1
p	.42	.46	.97
F2	<1	<1	<1
p	.48	.48	.88
number of NP3			
F1	**4.64**	2.20	<1
p	**.04**	.15	.84
F2	**6.74**	**3.97**	<1
p	**.01**	**.05**	.75
interaction: number NP2 × number NP3			
F1	2.28	<1	<1
p	.14	.64	.88
F2	**3.14**	<1	<1
p	**.09**	.62	.97



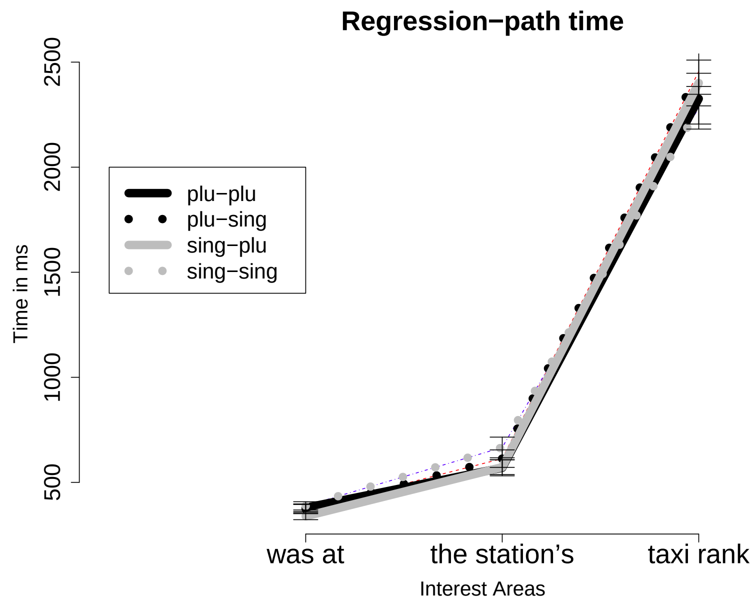
was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	critical	spillover	final
plural/plural	275.68	317.62	438.03
plural/singular	286.08	325.28	424.89
singular/plural	262.72	325.40	429.10
singular/singular	290.14	334.76	444.12

Figure 12: First-pass time in ms - Experiment 3

Table 23: F and p values for first-pass time - Experiment 3

F1/F2	critical	spillover	final
number of NP2			
F1	<1	<1	<1
p	.97	.50	.73
F2	<1	1.25	<1
p	.38	.27	.70
number of NP3			
F1	**3.36**	1.23	<1
p	**.08**	.28	.89
F2	**4.69**	1.62	<1
p	**.04**	.21	.90
interaction: number NP2 × number NP3			
F1	1.26	<1	1.54
p	.27	.96	.22
F2	1.30	<1	<1
p	.26	.95	.42



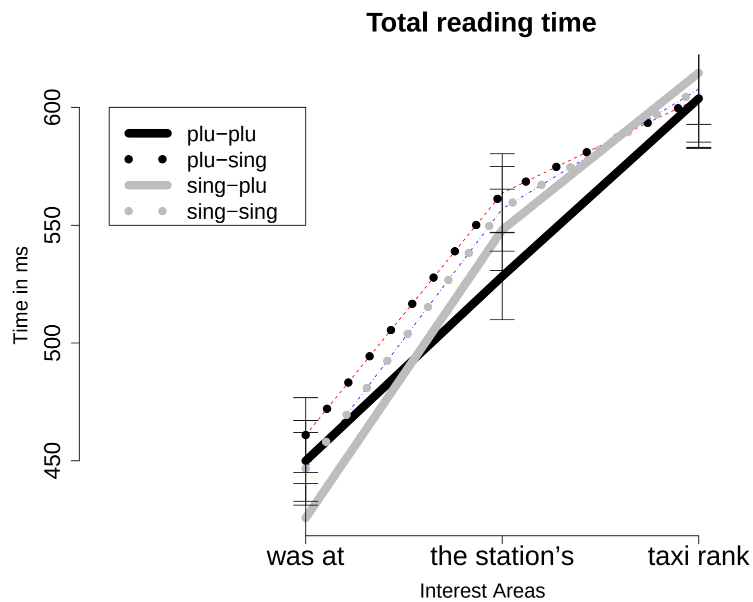
was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	**critical**	**spillover**	**final**
plural/plural	379.11	569.46	2326.16
plural/singular	372.84	613.02	2455.52
singular/plural	338.83	572.28	2400.85
singular/singular	388.22	666.20	2282.83

Figure 13: Regression-path time in ms - Experiment 3

Table 24: F and p values for regression-path time - Experiment 3

F1/F2	critical	spillover	final
number of NP2			
F1	<1	<1	<1
p	.96	.63	.41
F2	<1	<1	<1
p	.41	.41	.48
number of NP3			
F1	<1	**3.51**	<1
p	.41	**.07**	1.00
F2	1.00	2.64	<1
p	.33	.11	.87
interaction: number of NP2 × number of NP3			
F1	3.26	<1	<1
p	.08	.45	.34
F2	1.52	<1	1.83
p	.23	.42	.18



was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	critical	spillover	final
plural/plural	450.00	528.28	603.7539
plural/singular	460.95	563.67	603.86
singular/plural	425.76	548.00	614.64
singular/singular	446.64	556.92	607.77

Figure 14: Total reading time in ms - Experiment 3

6.2.1 Analysis of the critical region: `was at the`

The analysis of variance showed a main effect of number for the NP3 for first fixation duration: $F1(1,36) = 4.64$, $p < .05$; $F2(1,36) = 6.74$, $p < .05$. Reading times for sentences with a singular NP3 were read slower at the verb than those with a plural NP3. The effect of number for NP3 in first-pass time was marginally significant by subjects: $F1(1,36) = 3.36$, $p = .08$ and significant by items $F2(1,36) = 4.69$, $p < .05$. Again, conditions with a local singular noun preceding the verb had longer reading times than those with plural local nouns.

Table 25: F and p values for total reading time - Experiment 3

F1/F2	critical	spillover	final
number of NP2			
F1	1.28	<1	<1
p	.27	.70	.70
F2	**3.02**	<1	<1
p	**.09**	.57	.68
number of NP3			
F1	**2.88**	**3.21**	<1
p	**.10**	**.09**	.65
F2	2.12	**3.01**	<1
p	.15	**.09**	.65
interaction: number of NP2 × number of NP3			
F1	<1	<1	<1
p	.73	.42	.98
F2	<1	<1	<1
p	.51	.35	.78

Table 26: Means of comprehension question errors in Experiment 3

plur$_{NP2}$ - **plur**$_{NP3}$	**plur**$_{NP2}$ - **sing**$_{NP3}$	**sing**$_{NP2}$ - **plur**$_{NP3}$	**sing**$_{NP2}$ - **sing**$_{NP3}$
0.13	0.16	0.14	0.20

Table 27: F and p-values of comprehension question errors in Experiment 3

F / p	**NP2 effect**	**NP3 effect**	Interaction **NP2 × NP3**
F1(1,36)	2.73	**6.16**	0.64
p	.11	**.02**	.43
F2(1,36)	1.546	**7.42**	0.94
p	.22	<**.01**	.34

There was no effect of the number of NP2 in first fixation duration, first-pass time and regression-path time at the critical region. There was also no effect of the number of NP3 in regression-path time. The interaction between NP2 and NP3 was not significant for the first-pass time and total reading time,

6.2.2 Analysis of the spillover region: `the station's`

Analyses of variance of the total reading times showed an effect of the number of NP3 that was marginal by subjects: $F1(1,36) = 3.21$, $p = .08$; and marginal by items: $F2(1,36) = 3.01$, $p = .09$. The conditions with singular NP3 had longer reading times at the spillover region than the conditions with a plural NP3. There was no effect of the number of NP3 for first-pass time.

There was no effect of the NP2 observed in any of the measures: first fixation duration, first-pass time, regression-path time and total reading time. In addition, there was no interaction between the number NP2 and the number NP3 in any of the reported measures.

6.2.3 Analysis of the wrap-up region: `taxi rank`

The analyses of variance for first fixation duration, first-pass time, regression-path time and total reading times did not show any differences for number of the second noun phrase and of the local noun phrase. There was also no interaction between the NP2 and NP3 for first fixation duration, first-pass time, regression-path time and total reading time.

6.2.4 Analysis of the comprehension question errors

The analysis of variance showed a main effect of the number of NP3 by subjects $F1(1,36) = 6.16$, $p < .05$ and by items $F2(1,36) = 7.42$, $p < .01$. The means showed that conditions with a singular NP3 had a higher error rate than conditions with a plural NP3. There was no effect of the number of NP2 and there was no interaction.

6.3 Discussion of Experiment 3

The analysis of Experiment 3 showed an early effect of number of the NP3 in first fixation duration and in first-pass time at the critical region. There were longer reading times when the NP3 phrase was singular than when the NP3 phrase was plural. While this effect was only marginal in total reading times it was in the same direction. There were longer reading times at the verb when the NP3 was singular. The singular verb (*was*) is searching for its sentence subject (*chauffeur*), which must also be in singular. The findings in the reading time measures could be confirmed in the comprehension errors, there were more comprehension errors when the NP3 was singular than when the NP3 was plural. The finding that a singular NP3 in memory interferes with the retrieval of the singular subject supports the similarity based interference account. In addition, the number of NP2, which was the head of the prepositional phrase before the verb did not affect the reading times at the verb and the following regions. The reading time measures and the comprehension errors didn't indicate an effect of number attraction.

There might be two explanations for these findings. 1) Because the distance between NP2 and the main verb was large the activation of the NP2 might have decayed and therefore the number information of that noun phrase is unavailable and could not interfere with the number information of the NP3. 2) The structure of the materials used in Experiment 3 allowed for a potential confound. The embedded verb *advised* in (3) allows two subcategorisation frames. Some of the embedded verbs could be followed by a sentential complement rather than a direct object as is the correct analysis.

3. The janitor who advised (*that*) the apprentice of the carpenter was in the building this morning (*left*).

In the sentential complement analysis readers assume that the complex noun phrase (*the apprentice of the carpenter*) is the subject of the complement phrase (*the apprentice of the carpenter was in the building this morning*). At the end of the sentence, they realise that there is a main verb (like *left*) missing that the subject (*janitor*) needs to be integrated with. Thus, in this case readers would have to reanalyse their sentence analysis with the noun phrase (*the apprentice of the carpenter*) being the object of the verb *advised*. This misinterpretation of the subcategorisation analysis of the verb can potentially confound interference effects from the NP2. If readers analyse the NP2 (*the apprentice*) as the subject of the verb *was*, then there might be an attraction effect at the verb (*was*), which may cancel out interference.

In addition, the reanalysis of the sentence analysis might result in longer reading times and more regressions at the end of the sentence.

However, the interpretation of the complex NP as the subject of a sentence complement is normally not preferred to the interpretation as a direct object. In addition to that, not all verbs used in Experiment 3 (about half of them could take a sentence complement) allowed for this alternative interpretation. Therefore, the confounding effect of the ambiguity of the subcategorisation frames might not have been too likely. Nevertheless, Experiment 4 was conducted to repeat this experiment without the confound.

7 Experiment 4

Some of the sentences used in Experiment 3 contained a potential confound. Their embedded verbs (like *advised*) allowed two subcategorisation frames, which means that the following prepositional phrase could either be analysed as the object of the verb or the subject of a sentential complement. When the prepositional phrase is interpreted as the subject of the main verb, there might have been attraction at the main verb, which might mask interference effects from the NP2. Therefore, the materials from Experiment 3 were changed to be used in eye-tracking experiment 4. In order to avoid the ambiguity of Experiment 3, the embedded verbs were followed by a prepositional phrase (*argued with* in (2)) in Experiment 4. A preposition like *with* needs a noun phrase as a complement instead of sentence. Thus the ambiguity is avoided in Experiment 4.

1. The secretary / who phoned / the customers of the directors / was on / the train / to the meeting.

2. The secretary / who argued with / the customers of the directors / was on / the train / to the meeting.

The predictions that were formulated for Experiment 3 are the same for Experiment 4: similarity-based interference predicts that a similarity based interference effect when the noun phrases (NP2 *customer* and NP3 *director*) in memory are in singular and thus have the same number as the subject (*secretary*). There should be more interference from a singular NP3 than a singular NP2. There is more distance between the NP2 (*customer*) and the main verb (*was*) than between the NP3 (*director*) and the verb (*was*). Therefore the NP2 had more time to decay than the NP3 and the number information of NP2 less likely to interfere with the retrieval of the subject than the number information of the NP3.

If, however, it is number attraction that affects the processing of the main verb *was* than a plural noun phrase before the verb should be harder than a singular noun phrase. The attraction effect should be stronger from a plural NP2 than a plural NP3 since the NP2 is syntactically closer to the verb than the NP3.

7.1 Method

7.1.1 Participants

The data of forty undergraduate participants was analysed in this eye-tracking experiment. All of them were non-dyslexic English native speakers who received course credits for their participation.

7.1.2 Materials

For Experiment 4, 36 critical sentences were constructed. The sentence structure was similar to that used in Experiment 3, verbs followed by a prepositional phrase were used to avoid that comprehenders analyse NP2 as the subject of the main verb. In addition, some of the scenarios in the materials were changed to make them more plausible.

3. (a) **plural NP2 / plural NP3**
The secretary who argued with the customers of the directors was on the train to the meeting.

(b) **plural NP2 / singular NP3**
The secretary who argued with the customers of the director was on the train to the meeting.

(c) **singular NP2 / plural NP3**
The secretary who argued with the customer of the directors was on the train to the meeting.

(d) **singular NP2 / singular NP3**
The secretary who argued with the customer of the director was on the train to the meeting.

The areas of interest were similar to Experiment 3.

Table 28: Areas of interest for Experiment 4

critical	**spillover**	**final**
was on	the train	to the meeting.

In addition, the pattern of comprehension questions and the fillers used in Experiment 4 were similar to those used in Experiment 3.

7.1.3 Design

The design of Experiment 4 was the same as in Experiment 3: a 2×2 within-subjects design. The number feature of the two embedded nouns was manipulated: variable one was the number marking for the NP3 *the politician(s)* (singular vs plural) and variable two for the NP2 *the assistant(s)* (singular vs plural). The conditions of the critical sentences were distributed over four different lists in such a way that each list contained all critical but in a different condition. The design of the materials was identical to the Experiment 3.

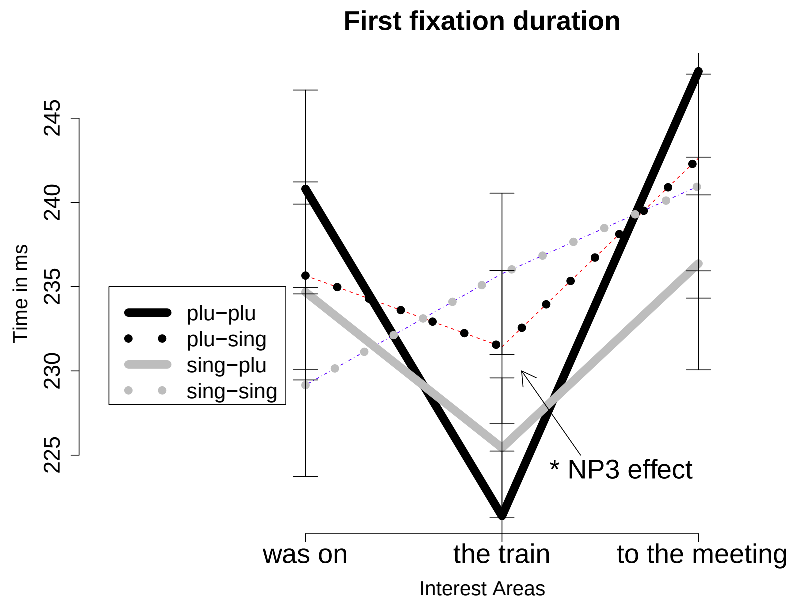
7.1.4 Apparatus and procedure

The same eye-tracker and procedure as described in the previous experiments were used in Experiment 4.

7.2 Results

Measures used for analysis were: first fixation duration, first-pass time, regression-path time and total reading time. A detailed definition of these measures can be found in the results section of Experiment 1.

Figures 15, 16, 17 and 18 show the reading times for first fixation duration, first-pass time, regression-path time and total reading time respectively on the different areas of interest. The Table 33 gives the means of the comprehension question errors. Tables 29 (first fixation duration), 30 (first-pass time), 31 (regression-path time), 32 (total reading time) and 34 (comprehension question errors) show the F- and p values of the analyses of variance.



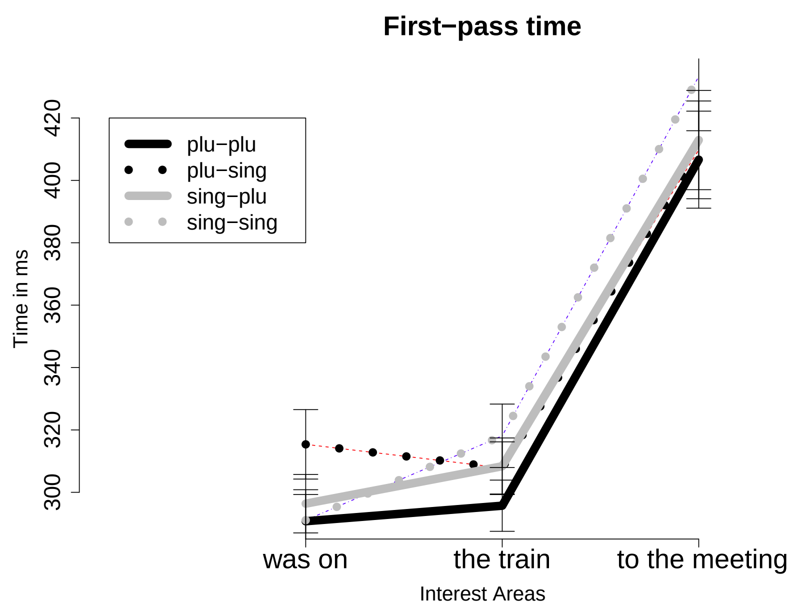
was on	the train	to the meeting.
critical	spillover	final

number NP2 / number NP3	**critical**	**spillover**	**final**
plural/plural	240.80	221.39	247.79
plural/singular	235.66	231.43	242.63
singular/plural	234.68	225.43	236.38
singular/singular	229.16	235.77	240.97

Figure 15: First fixation duration in ms - Experiment 4

Table 29: F and p values for first fixation duration - Experiment 4

F1/F2	critical	spillover	final
number of NP2			
F1	1.26	1.50	1.24
p	.27	.23	.27
F2	1.65	<1	1.64
p	.21	.37	.21
number of NP3			
F1	<1	**4.17**	<1
p	.34	<**.05**	.91
F2	1.29	**13.70**	<1
p	.26	<**.01**	.91
interaction: number NP2 × number NP3			
F1	<1	<1	<1
p	.60	.56	.58
F2	<1	<1	1.09
p	.97	.98	.31



was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	critical	spillover	final
plural/plural	290.73	295.70	406.64
plural/singular	315.37	307.82	409.79
singular/plural	296.36	308.35	412.93
singular/singular	291.06	318.11	433.31

Figure 16: First-pass duration in ms - Experiment 4

Table 30: F and p values for first-pass time - Experiment 4

F1/F2	critical	spillover	final
number of NP2			
F1	<1	2.39	<1
p	.57	.13	.56
F2	<1	1.61	<1
p	.36	.21	.60
number of NP3			
F1	<1	2.26	<1
p	.83	.14	.49
F2	**3.00**	1.46	1.46
p	**.09**	.24	.24
interaction: number NP2 × number NP3			
F1	<1	<1	<1
p	.34	.72	.57
F2	2.12	<1	<1
p	.16	.96	.56

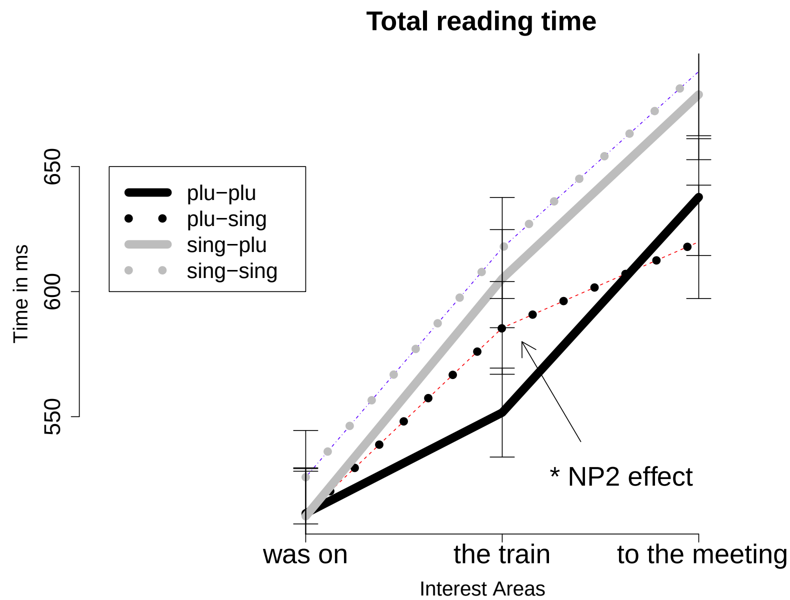
was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	critical	spillover	final
plural/plural	510.72	782.25	2796.40
plural/singular	480.60	766.04	2814.24
singular/plural	468.91	822.70	2985.54
singular/singular	544.50	855.53	3019.35

Figure 17: Regression-path duration in ms - Experiment 4

Table 31: F and p values for regression-path time - Experiment 4

F1/F2	critical	spillover	final
number of NP2			
F1	<1	1.92	1.14
p	.73	.18	.29
F2	<1	1.88	2.20
p	.66	.18	.15
number of NP3			
F1	<1	<1	<1
p	.36	.70	.55
F2	<1	<1	<1
p	.61	.88	.76
interaction: *number NP2 × number NP3*			
F1	3.33	<1	<1
p	.08	.41	.94
F2	1.21	<1	<1
p	.28	.60	.81



was at	the station's	taxi rank
critical	spillover	final

number NP2 / number NP3	critical	spillover	final
plural/plural	511.35	551.64	637.79
plural/singular	510.91	585.48	619.90
singular/plural	510.19	605.19	678.81
singular/singular	525.79	617.44	688.02

Figure 18: Total reading time in ms - Experiment 4

Table 32: F and p values for total reading time - Experiment 4

F1/F2	critical	spillover	final
number of NP2			
F1	<1	**4.61**	**4.41**
p	.78	**.04**	**.04**
F2	<1	**6.00**	2.30
p	.74	**.02**	.14
number of NP3			
F1	<1	<1	<1
p	.91	.36	.51
F2	<1	1.01	<1
p	.63	.32	.93
interaction: *number of NP2 × number of NP3*			
F1	1.32	<1	<1
p	.26	.68	.43
F2	<1	<1	<1
p	.70	.44	.67

Table 33: Means of comprehension question errors in Experiment 4

plur$_{NP2}$ - **plur**$_{NP3}$	**plur**$_{NP2}$ - **sing**$_{NP3}$	**sing**$_{NP2}$ - **plur**$_{NP3}$	**sing**$_{NP2}$ - **sing**$_{NP3}$
0.12	0.14	0.11	0.18

Table 34: F and p-values of comprehension question errors in Experiment 4

F / p	**NP2 effect**	**NP3 effect**	**interaction: NP2 and NP3**
F1(1,36)	0.83	**13.63**	1.99
p	.37	<**.001**	.17
F2(1,32)	0.29	**4.23**	1.45
p	.59	<**.05**	.24

7.2.1 Analysis of the critical region: `was on`

The measures first fixation duration, regression-path time and total reading time did not show an effect of the NP3 at the critical region. None of the measures reported here (first fixation duration, first-pass time, regression-path time and total reading time) showed an effect of the number of the NP2 and they did not show an interaction between the number of the NP3 and the number of the NP2.

7.2.2 Analysis of the spillover region: `the train`

Analyses of variance of first fixation duration by subjects and by items returned a main effect of number of the NP3 $F1(1,36) = 4.17$, $p < .05$; $F2(1,32) = 13.70$, $p < .01$. Conditions with a singular NP3 (that matched the number of the singular sentence subject) had longer reading times at the spillover region than the conditions with a plural NP3.

Furthermore, the analyses of total reading times showed a main effect of the NP2 for total reading time, $F1(1,36) = 4.61$, $p < .05$; $F2(1,32) = 6.00$, $p < .05$. There were longer total reading times when the number of the NP2 was singular and thus matched the number of the sentence subject than when the number of the NP2 was plural and thus did not match the number of the sentence subject.

There were no main effects or interactions in any of the other measures.

7.2.3 Analysis of the final region: `to the meeting`

The effect of the number of the NP2 was significant by subjects in total reading time: $F1(1,36) = 4.41$, $p < .04$; but not significant by items in total reading time: $F2(1,32) = 2.30$, $p = .14$. There were longer reading times when the NP2 was singular and thus the number of the NP2 matched the number of the singular sentence subject than when the NP2 was plural.

There were no main effects (of the number of the NP2 or the number of the NP3) or interactions (between the number of the NP2 and the number of the NP3) in any of the other measures.

7.2.4 Analysis of the comprehension question errors

Analyses of variance of the comprehension question errors in Experiment 4 showed a main effect of number of NP3 by subjects $F1(1,36) = 13.63$, $p < .001$ and by items $F(1,32) = 4.23$, $p < .05$. Table 33 shows that conditions with a singular NP3 had a higher error rate than the conditions with a plural NP3. There was no effect from the number of the NP2 nor an interaction between the variables in the comprehension question errors.

7.3 Discussion of Experiment 4

Like in Experiment 3, Experiment 4 showed an early effect of number interference in first fixation duration that was caused by the local noun phrase *director*. When the number of the NP3 matched the number of the singular sentence subject, there were longer first fixation durations on the spillover region. The findings in the comprehension errors supported the findings in the reading times measures: there were higher error rates when the NP3 was singular than when it was plural. In addition, there was also an interference effect of the NP2. Total reading times were longer at the spillover region when the head of the prepositional phrase was singular and thus matched the number of the sentence subject.

These findings do not provide evidence for a number attraction effect. The early measure first fixation duration showed that a singular NP3 caused a slowdown at the spillover region, but attraction would have predicted that the presence of a plural NP3 should induce longer reading times. Therefore, it is the retrieval cue based parsing account that explains the data best.

The findings of Experiment 3 and 4 showed that number interference affects sentence comprehension. If number attraction affected comprehension processes in Experiments 3 and 4, it is weak and might have been masked by interference. Experiments 1 and 2 showed a weak number interference effect (interaction only in Experiment 2 in first-pass time) and it occurred later than the effect caused by the relative clause type. A crucial difference between the first two experiments and Experiment 3 and 4 is the distance between the subject and its verb. Number interference caused by NP3 occurred early in Experiment 3 and 4 (in first fixation duration). The NP3 directly preceded the critical verb and therefore its number information was still active to interfere with the subject retrieval. When the NP3 in memory has the same number as the subject that needs to be retrieved, there will be longer reading times than when the number information of the NP3 is mismatching with the number of the subject noun.

In addition to the early interference effect of the NP3, there was also an interference effect from the NP2 in total reading times at the spillover region. The NP2 is more distant to the main verb than the NP3. The activation of the number information might have decayed more and therefore this effect only occurs in the later measure of total reading times. There was no interference effect from the NP2 in Experiment 3, which might have been due to some of the verbs used in Experiment 3 (Some of the embedded verbs allowed for two subcategorisation frames, which might have caused readers to interpret the prepositional phrase as the subject of the main verb. With the prepositional phrase as the subject, there might have been attraction effects from the NP2 that override any effects of interference from the NP2.). Since the embedded verbs used in Experiment 4 were followed by a prepositional phrase, this ambiguity was avoided in Experiment 4. However, the interference effect observed for the NP2 did not occur as early as the interference effect from the NP3. Because the NP2 is more distant to the verb, its information might have decayed over time and therefore is not as readily available as the information of the NP3. Even though, the information might have decayed the number information of the NP2 still interferes with later processing. Therefore, the interference effect of the NP2 might be part of later checking processes.

8 Experiment 5

In sentence processing, retrieval cue parsing accounts predict that processing difficulty occurs due to interference between similar noun phrases at verb integration (Van Dyke & Lewis, 2003; Lewis & Vasishth, 2005; Van Dyke, 2007). The first two experiments in this thesis showed only a weak number interference effect that interacted with sentence complexity. While there was a main effect of relative clause type observed early (in the early measures and on the critical and the following regions), the interference effect was only observed at the final region of Experiment 2 in first pass time. Therefore, it was suggested that number interference might be associated with sentence final integrative wrap-up processes. However, increasing the distance between the verb and its subject in Experiments 3 and 4 resulted in an effect of number interference that occurred early. Van Dyke and Lewis (2003) and Lewis and Vasishth (2005) suggested that retrieval cue overlap from different types such as verb subcategorisation, semantics, number, animacy should all cause interference simultaneously.

However, these assumptions are inconsistent with the observations reported in Van Dyke (2007) where it was found that structural interference occurred before semantic interference. Using eye-tracking Van Dyke tested materials with a complement phrase that either contained a relative clause containing a prepositional phrase (*near the dangerous warehouse/neighbor* in (1a) and (1b), low syntactic interference condition) or another complement phrase (*that the warehouse/neighbor was dangerous* in (1c) and (1d), high syntactic interference condition). Thus, Van Dyke tested similarity based interference caused by the subcategorisation information of the verb in the complement phrase: *was living* was followed by a prepositional phrase in the conditions (1a) and (1b), whereas *said* was followed by a complement phrase in (1c) and (1d). According to Van Dyke a syntactic interference effect occurs when the retrieval cues from the verb *was* cannot identify the target subject *the resident*. In the syntactically high interfering conditions (1c) and (1d) the complement phrase contained a noun that was a subject *warehouse / neighbor*. Thus, the presence of an interfering subject item creates more syntactic interference in (1c) and (1d) than the presence of an item that is not a subject in (1a) and (1b).

In addition to sentence complexity, Van Dyke manipulated the retrieval cues of the noun phrases, they were either all animate (*worker, resident* and *neighbor* in (1b) and (1d)) noun phrases or the last noun phrase was inanimate (*warehouse* in (1a) and (1c)). Animate noun (*worker, resident*) phrases are a better semantic fit for the verb phrase *was complaining*. The inanimate noun phrase *warehouse* is less likely *to complain* than the animate *worker* or *resident*.

1. (a) **low syntactic interference / low semantic interference**
   The worker was surprised that the resident | who was living near the dangerous warehouse | was complaining | about the | investigation.

   (b) **low syntactic interference / high semantic interference**
   The worker was surprised that the resident | who was living near the dangerous neighbor | was complaining | about the | investigation.

   (c) **high syntactic interference / low semantic interference**
   The worker was surprised that the resident | who said that the warehouse was dangerous | was complaining | about the | investigation.

   (d) **high syntactic interference / high semantic interference**
   The worker was surprised that the resident | who said that the neighbor was dangerous | was complaining | about the | investigation.
   (Van Dyke, 2007, p. 409),

Van Dyke (2007) reported an effect of syntactic interference at the critical region (*was complaining*) in first-pass, regression-path and total reading time. In addition, there was also an effect of the syntactic manipulation on regressive eye movements. There were longer reading times and more regressive eye movements in the high syntactic interference condition than in the low syntactic interference condition. In addition, there was also an effect of semantic interference, but this was observed at the spillover region (*about the*) in first-pass and regression-path time. These findings suggest that different types of retrieval cues do not have an effect at the same time. From the findings of Van Dyke (2007), it seems that retrieval cues for syntactic information become available before the semantic cues. Thus, similarity based interference due to the subcategorisation information of the verb was observable before the interference due to overlap of the semantic information. The retrieval cue overlap effect of the information about the animacy of a noun was observed late. Thus, the early syntactic effect found in Van Dyke can be related to the early syntactic effect presented in the first two experiments of this thesis: Experiments 1 and 2 showed that the relative clause effect occurred before the number interference effect. However, the distance between the subject and its verb were very small in Experiments 1 and 2 and therefore the subject did not have enough time to decay. In contrast Experiment 3 and 4 showed an early number interference effect when the distance between the subject and its verb were increased and thus the subject had more time to decay.

However, the late effect of semantic interference reported by Van Dyke (2007) might be confounded by another factor. In their sentence materials Van Dyke (2007) manipulated the animacy of noun phrases, however inanimate noun phrases are sometimes improbable agents in contrast to animate noun phrases. In (1) Van Dyke contrasted the animate *neighbor* with the inanimate *warehouse* to investigate interference with the subject *resident* at the verb *was complaining*. In addition to being inanimate, the *warehouse* itself is very unlikely to be *complaining* and therefore is an improbable interfering subject for *complaining*. The probability of the interfering noun phrase as an agent might be a confound for the interference effect. Since readers might exclude *warehouse* as an implausible subject of *complain*, this might be an effect of implausibility and not an effect of memory interference.

The number information of noun phrases provides another testable cue to investigate retrieval interference. The findings of Van Dyke (2007) suggested that interference effects due to different cue overlap might occur at different times. The semantic interference effect in Van Dyke (2007) occurred later after the interference effect due to syntactic cue overlap. The approach of Van Dyke and Lewis (2003) claimed that retrieval interference effects due to different cue overlaps should occur simultaneously. However the findings of Van Dyke (2007) suggest that interference effects occur at different times. The research question for Experiment 5 of this thesis is: When do number interference effects occur in relation to the syntactic effect due to the overlapping subcategorisation information? The number interference effect occurred early in Experiment 3 and 4. In addition, number information might be used in early syntactic processes to compute agreement between a subject and its verb. Thus, Experiment 5 will investigate the timing of the number interference effect in comparison with a syntactic effect due to verb subcategorisation information overlap similar to materials in Van Dyke (2007).

In Experiment 5, number information of the noun phrases will be used to investigate the time course of structural and number interference effects during sentence processing. The number information will be used to test whether, like the information about noun phrase animacy, number information will cause interference later than verb sub-categorisation information. The findings of Van Dyke (2007) and the findings of Experiments 1 and 2 suggest that number information might be used later after the relative clause (Experiments 1 and 2) or after the syntactic interference effect (Van Dyke, 2007). However, the findings of Experiments 3 and 4 suggest that the number information might be used early when the subject had enough time to decay (due to the longer distance between the subject and the verb).

2. (a) **low syntactic / nr incongruent**
   The presenter acknowledged that the photographer who was chatting with the convincing journalists has been awarded the prize.

(b) **low syntactic / nr congruent**
The presenter acknowledged that the photographer who was chatting with the convincing journalist has been awarded the prize.

(c) **high syntactic / nr incongruent**
The presenter acknowledged that the photographer who professed that the journalists talked convincingly has been awarded the prize.

(d) **high syntactic / nr congruent**
The presenter acknowledged that the photographer who professed that the journalist talked convincingly has been awarded the prize.

8.1 Method

The method was the same to those used in the previous experiments.

8.1.1 Participants

Forty English native speakers took part in this eye tracking experiment. These native speakers were undergraduate students of Psychology at the University of Dundee and received course credits in exchange for their participation. They were non-dyslexic with normal or corrected to normal vision.

8.1.2 Materials

For Experiment 5, 40 critical sentences were create. See Table 35 for a sample sentence in the four conditions. Each sentence had a singular subject (*presenter*) followed by the main verb (*acknowledged*) and a complement phrase starting with *that the photographer*. The noun *photographer* is the subject of the complement phrase and always singular. The complement phrase contained the manipulations of Experiment 5. The complement phrase contains a subject relative clause that contains a prepositional phrase in the syntactically low interfering conditions (*with the convincing journalist(s)*) or another complement phrase in the syntactically high interfering conditions (*that the journalist(s) talked convincingly*). In addition, the number information of the noun phrase in the prepositional phrase and the complement phrase was manipulated (*journalist(s)*). When these noun phrases were singular (*journalist*) then they were number congruent with the subject of the first complement phrase (*photographer*). When these noun phrase were plural, they were number incongruent with the singular *photographer*. After the embedded prepositional phrase or the complement phrase, the verb of the first complement phrase followed (*has been awarded*). This has to agree in number with the subject (*the photographer*) of the complement phrase. Finally, there is the object of the complement phrase (*the prize*).

The areas of interest in Experiment 5 were similar to those described by Van Dyke (2007). The intro area contained the sentence subject, the main verb and the beginning of the complement phrase (*The presenter acknowledged that the photographer*). The following region contained a relative clause with the manipulation: either a prepositional phrase and an object in singular or plural (*who was chatting with the convincing journalist(s)*) or a complement phrase with either singular or plural subject (*who professed that the journalist(s) talked convincingly*).

While Van Dyke (2007) included a precritical region (*yesterday afternoon in Table 35*) to avoid having verb phrases next to each other, this precritical region was omitted in Experiment 5. The reason is that the pre-critical region (*yesterday afternoon* in Van Dyke) adds a global ambiguity to the high syntactic conditions. In the example given in Table 35, the attachment site for *yesterday afternoon* is ambiguous: it can be attached high to *remembered* or low to *who was sitting in the smelly seat*. Readers may resolve the ambiguity differently in the high and low syntactic condition (Van Gompel, Pickering, & Traxler, 2001). Therefore, the sentences in Experiment 5 were presented without a precritical region like *yesterday afternoon*.

The area with the manipulation was followed by the critical region that contained the verb auxiliary which is number marked (*has been*). This is followed by the spillover region which contained the verb *followed*. The final region contained the object (*the prize*) of the first complement phrase.

Table 35: Experimental item of Experiment 5

Experimental item Van Dyke (2007)	**Experimental item from Experiment 5**
Intro:	**Intro:**
The pilot remembered that the lady	The presenter acknowledged that the photographer
LoSyn / LoSem	*LoSyn / nr incongruent*
who was sitting in the smelly seat	who was chatting with the convincing journalists
LoSyn / HiSem	*LoSyn / nr congruent*
who was sitting near the smelly man	who was chatting with the convincing journalist
HiSyn / LoSem	*HiSyn / nr incongruent*
who said that the seat was smelly	who professed that the journalists talked convincingly
HiSyn / HiSem	*HiSyn / nr congruent*
who said that the man was smelly	who professed that the journalist talked convincingly
pre-critical	**pre-critical**
yesterday afternoon	...
critical	**critical**
moaned	has been
spillover	**spillover**
about a refund	awarded
final	**final**
for the ticket.	the prize.

LoSyn = low syntactic interference condition, *HiSyn* = high syntactic interference condition, *LoSem* = Low semantic interference condition, *HiSem* = Low semantic interference condition

In addition to the critical sentences, 65 filler sentences were presented and each sentence was followed by a yes/no comprehension question. These comprehension questions asked for information that was provided in the previous sentence. 50% were Yes- and 50% were No-comprehension questions.

Table 36 shows the different types of comprehension questions that were asked in Experiment 5. Those were six different types of comprehension questions three of these required a "yes" response and three a "no" response. These were equally distributed, thus there were twenty yes-questions and twenty no-questions. Given the sample sentence below, there were three different kinds of "yes" and three different kinds of "no" comprehension questions that could have been asked.

Table 36: Comprehension questions - Experiment 5

The presenter acknowledged that the photographer who professed that the journalist talked convincingly has been awarded the prize.

Yes-questions	**No-questions**
(a) Did the journalist talk convincingly?	(a) Did the journalists talk convincingly?
(b) Was the photographer awarded the prize?	(b) Has the director been awarded the prize?
(c) Did the photographer profess something about the journalist?	(c) Did the journalist profess something about the photographer?

8.1.3 Design

Eye-tracking Experiment 5 had a 2 × 2 design. The first variable was structural complexity, the subject relative clause either contained a prepositional phrase (*with the convincing journalists* is less complex) or a sentence complement (*that the journalists talked convincingly* is more complex). The second variable was the number of the embedded noun, which was either singular and thus matched the number of the subject (*journalist*) or plural and therefore mismatched the number of the sentence subject (*journalists*).

Four lists with all items were created. Each list contained forty critical items and the four conditions were equally distributed over the lists. Each list contained all the critical items, but in a different condition. Ten participants were assigned at random to each list. Eighty five filler sentences were presented in addition to the critical items. The order of the critical and the filler items in the four lists was randomised, though this order did not differ between lists. After the presentation of each sentence, a Yes/No question asked for the comprehension of the previous sentence.

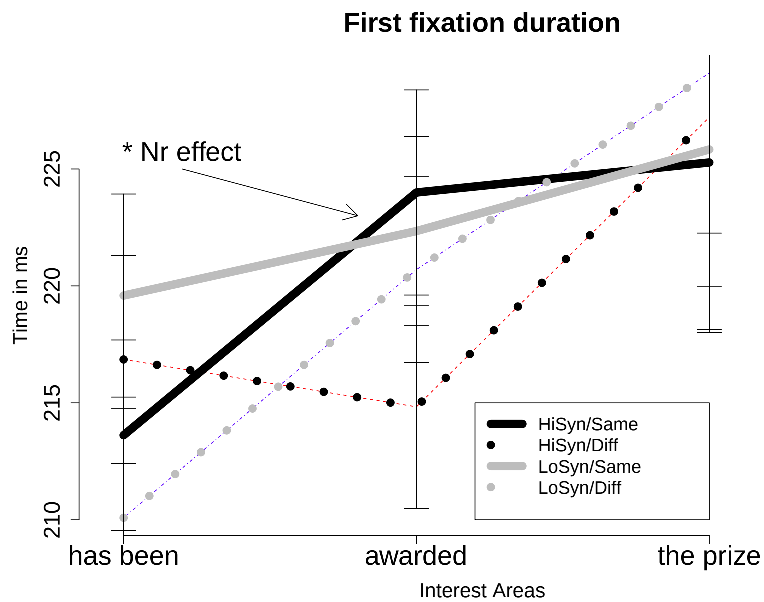
8.1.4 Apparatus and procedure

Apparatus and procedure of Experiment 5 were identical to the previous four eye tracking experiments.

8.2 Results

Analyses of variance were conducted with subjects (F1) and items (F2) as random variables like in the previous experiments. Sentence complexity (sentences were either high syntactically interfering or low syntactically interfering) and number congruency (the number of the embedded noun phrase either matched or mismatched the sentence subject) were treated as within-subject and within-item fixed variables. Furthermore, subject group was treated like in the previous experiments, fixed between subject variables in by-subject analyses. The same applies to item group which was fixed between the item variable in the by-item analyses. Fixations shorter than 30ms were excluded from the analysis.

Figures 19, 20, 21 and 22 show the different reading time measures (19: *first fixation duration*, 20: *first-pass time*, 21: *regression-path time* and 22: *total reading time*) on the areas of interest (critical: *has been*, spillover: *awarded*, final: *the prize*) for Experiment 5. Table 41 gives the means for the comprehension question errors. Tables 37 (first fixation duration), 38



has been	awarded	the prize
critical	spillover	final

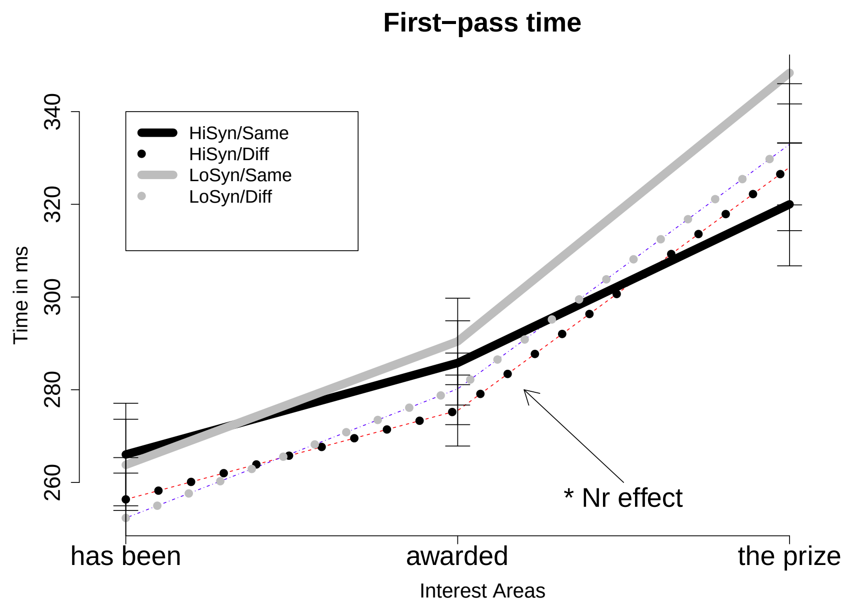
condition	critical	spillover	final
complex/same	213.31	224.06	226.47
complex/different	216.47	215.48	227.17
simple/same	219.54	222.35	229.46
simple/different	209.57	220.34	229.68

Figure 19: First fixation duration means in ms - Experiment 5

(first-pass time), 39 (regression-path time), 40 (total reading time) and 42 (comprehension question error) show the p- and F-values of the by-subject and the by-item analyses of variance of Experiment 5.

Table 37: F and p values for first fixation duration - Experiment 5

F1/F2	critical	spillover	final
Complexity of structure			
F1	<1	<1	<1
p	.98	.90	.45
F2	<1	<1	<1
p	.83	.99	.53
number match			
F1	<1	**4.37**	<1
p	.66	**.04**	.80
F2	<1	**3.94**	<1
p	.51	**.05**	.63
interaction: complexity × number match			
F1	<1	<1	<1
p	.50	.55	.86
F2	1.00	<1	<1
p	.32	.48	.79



has been	awarded	the prize
critical	spillover	final

condition	critical	spillover	final
complex/same	268.28	288.45	325.57
comlex/different	257.92	276.12	328.04
simple/same	266.68	289.43	355.20
simple/different	252.97	283.54	335.01

Figure 20: First-pass time means in ms - Experiment 5

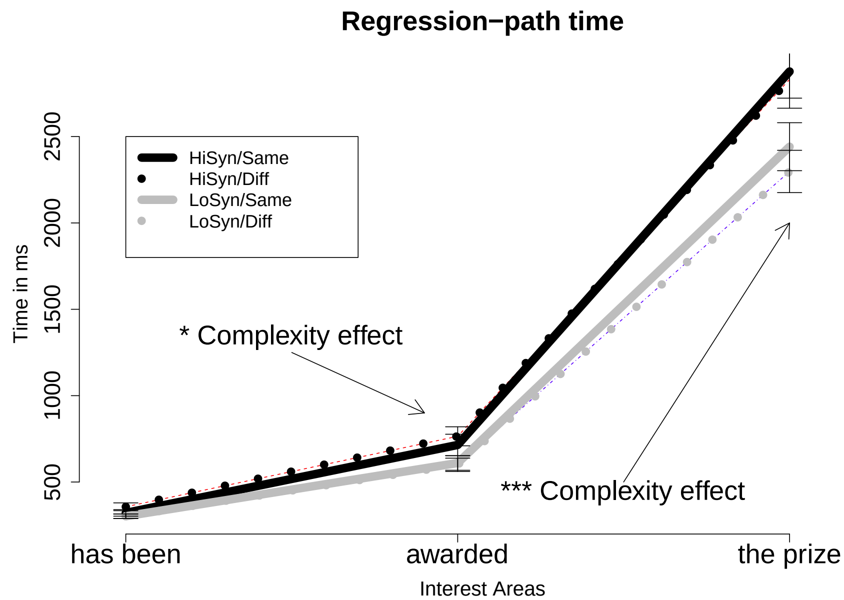
8.2.1 Analysis of the critical region: `has been`

There was a main effect of structural complexity in total reading time: F1(1,36) = 36.00, $p < .001$; F2(1,36) = 26.73, $p < .001$. Reading times for the complex conditions were significantly longer than those for the structurally simpler conditions.

Analyses of variance also showed a marginal structural effect by items for regression-path time: F2(1,36) = 2.92, p = .096, which was not significant by subjects. The structurally more complex conditions took longer to read than the simpler structures.

Table 38: F and p values for first-pass time - Experiment 5

F1/F2	critical	spillover	final
complexity of structure			
F1	<1	<1	**3.12**
p	.81	.98	**.09**
F2	<1	<1	**3.60**
p	.98	.88	**.07**
number match			
F1	<1	**6.00**	1.21
p	.46	**.02**	.28
F2	<1	**4.08**	<1
p	.38	**.05**	.47
interaction:			
complexity × number match			
F1	<1	<1	<1
p	.94	.54	.38
F2	<1	<1	<1
p	1.00	.48	.33



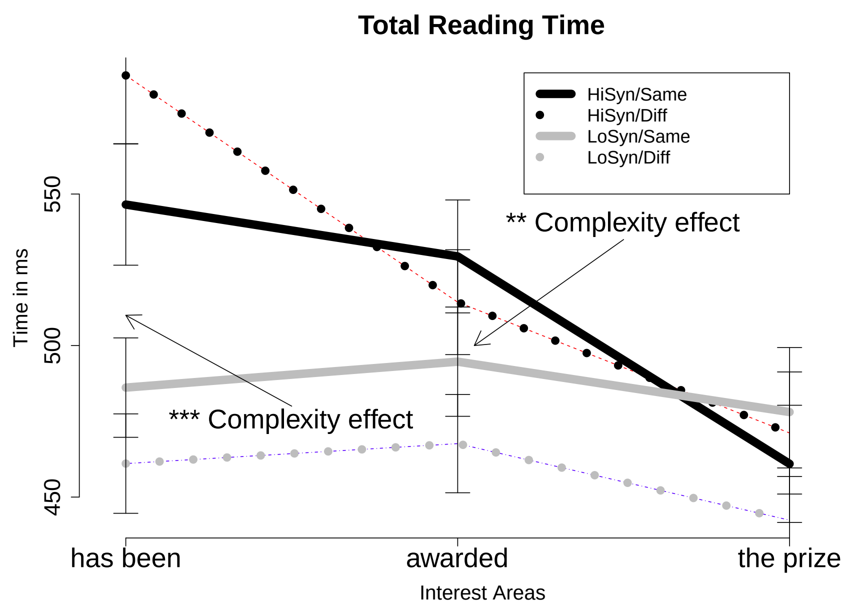
has been	awarded	the prize
critical	spillover	final

condition	critical	spillover	final
complex/same	315.08	698.58	2975.15
complex/different	348.26	762.50	2948.88
simple/same	303.43	592.74	2526.35
simple/different	300.77	597.63	2310.29

Figure 21: Regression-path time means in ms - Experiment 5

Table 39: F and p values for regression-path time - Experiment 5

F1/F2	critical	spillover	final
complexity of structure			
F1	2.66	**5.68**	**15.76**
p	.11	**.02**	<**.001**
F2	**2.92**	**8.04**	**27.21**
p	**.10**	**.01**	<**.001**
number match			
F1	**3.26**	<1	1.82
p	**.08**	.86	.19
F2	1.47	<1	<1
p	.23	.85	.43
interaction:			
complexity × *number match*			
F1	<1	<1	<1
p	.34	.54	.45
F2	<1	<1	1.01
p	.36	.64	.32



has been	awarded	the prize
critical	spillover	final

condition	critical	spillover	final
complex/same	552.39	531.43	473.29
complex/different	590.92	519.66	478.53
simple/same	490.92	492.94	488.87
simple/different	459.59	471.92	447.24

Figure 22: Total reading time means in ms - Experiment 5

Table 40: F and p values for total reading time - Experiment 5

F1/F2	critical	spillover	final
sentence complexity			
F1	**36.00**	**10.85**	<1
p	<**.001**	<**.005**	.70
F2	**26.73**	**15.56**	<1
p	<**.001**	<**.001**	.50
number match			
F1	<1	**3.28**	2.30
p	.68	**.079**	.14
F2	<1	1.82	1.17
p	.65	.19	.29
interaction: complexity × number match			
F1	5.29	<1	1.54
p	.03	.61	.22
F2	2.58	<1	2.47
p	.12	.58	.12

Table 41: Means of comprehension question errors in Experiment 5

complex - same	complex - different	simple - same	simple - different
0.18	0.24	0.18	0.23

Table 42: F and p-values of comprehension question errors in Experiment 5

F / p	**complexity**	**nr match**	**interaction: complexity and nr match**
F1(1,36)	0.11	**8.02**	0.03
p	.74	<**.01**	.86
F2(1,36)	0.06	**5.43**	<1
p	.81	**.03**	.96

There were no other main effects or interactions in any of the other measures at the critical region.

8.2.2 Analysis of the spillover region: `awarded`

Anova's showed a main effect of number match on first fixation duration on the spillover region that was significant by subjects: $F1(1,36) = 4.37$, $p < .05$; but marginal by items: $F2(1,36) = 3.94$, $p = .05$. The means of conditions with noun phrases that were the same in number were longer than the means for conditions with mismatching noun phrases. There was another effect of number match for first-pass time. It was significant by subjects: $F1(1,36) = 6.00$, $p < .05$; by items the effect was marginal: $F2(1,36) = 4.08$, $p = .05$. Conditions with noun phrases matching in number had longer reading times than the conditions with mismatching noun phrases.

The analyses of variance returned a main effect of structural complexity for regression-path time: $F1(1,36) = 5.68$, $p < .001$; $F2(1,36) = 27.21$, $p < .001$.The structurally more complex conditions took longer than the simpler conditions. Furthermore, the analyses of total reading time at this position showed a main effect of syntactic complexity: $F1(1,36) = 10.85$, $p < .005$; $F2(1,36) = 15.56$, $p < .001$. The more complex sentences were read slower at this position. The comparison for the number match conditions on total reading times showed an effect that was marginal by subjects: $F1(1,36) = 3.28$, $p = .08$; the difference by items was not marginally significant.

There were no main effects in any of the other measures. There were no interactions in any of the measures analysed here.

8.2.3 Analysis of the final region: `the prize`

The analyses of variance for the reading time measures on the final region showed an effect of syntactic complexity on first-pass time, which was marginal by subjects: $F1(1,36) = 3.12$, $p = .086$; and also marginal by items: $F2(1,36) = 3.60$, $p = .066$. Here, the conditions with the simpler syntactic structure were read more slowly than the complex conditions. There was also a main effect of syntactic structure in regression-path time: $F1(1,36) = 15.76$, $p < .001$; $F2(1,36) = 27.21$, $p < .001$. The complex syntactic conditions were harder to read than the syntactically simpler conditions.

There were no effects of syntactic complexity in first fixation duration and total reading time. Analyses of variance did not show any significant differences for the number match manipulation in first fixation duration, first-pass time, regression-path time and total reading time. Finally, the analyses did not show any interaction effects between the structural factor and the number congruency factor for first fixation duration, first-pass time, regression-path time and total reading time.

8.2.4 Analysis of the comprehension question errors

Analyses of variance showed a main effect of number congruency by subjects $F1(1,36) = 8.02$, $p < .01$ and by items $F2(1,36) = 5.43$, $p < .05$. Incongruent number conditions had higher error rates than the congruent number conditions. There was no effect of syntactic complexity and no interaction between the two variables (number congruency and syntactic complexity.)

8.3 Discussion of Experiment 5

The main findings of Experiment 5 are a main effect of number interference at the spillover region (*awarded*) in first fixation duration and in first-pass time. Number congruent conditions had longer reading times than number incongruent conditions. In addition, there was a main effect of structural complexity at the critical region (*has been*) in total reading time, at the spillover region (*awarded*) in total reading and in regression-path time and at the final region (*the prize*) in regression-path time. Syntactically high interfering conditions were read longer than syntactically low interfering conditions.

The findings in the comprehension errors showed that conditions with a plural embedded noun had a higher error rate than the conditions with a singular embedded nouns. These findings are not in agreement with the effects in the reading time measures. There are two possible explanations for these findings. (1.) The inconsistency might be due to the offline nature of comprehension questions and online reading times. Online reading times showed an early effect of number congruency: there were longer reading times when the embedded noun phrase was singular than when it was plural. These longer reading times for singulars might trade-off later with better comprehension scores. Plurals, on the other hand, might initially have shorter reading times, but this might be paid with poorer overall comprehension in the end. (2.) The longer reading times of the mismatching conditions might also be due to number attraction. In the number incongruent conditions, the singular verb *has* is preceded by a plural noun (*journalists* - either also in subject position in the syntactically complex condition or as part of a prepositional phrase). The sentences used in Experiment 5 were long with syntactically complex structures (the more complex sentences had relative clauses embedded in relative clauses which then were embedded in a complement phrase). Thus, the embedded plural noun might have been especially marked in memory and therefore erroneously interpreted as the subject of the main verb, resulting in a higher error rate. These are two potential explanations why the error rate of the number incongruent conditions (plural embedded noun) had a higher error rate than the number congruent conditions (singular embedded noun).

While the observations of a structural and a number interference effect seem to be in agreement with the study by Van Dyke (2007), the order (number interference occurred early in first fixation and first-pass time and the syntactic interference effect later in regression-path time and total reading time) of the effects are not in agreement with the findings of Van Dyke. Van Dyke reported effects of the structural manipulation in the measures of first-pass and regression-path time on the critical region, in the current experiment there was no effect of syntactic complexity in the early first-pass time on the critical region. Total reading time showed an effect of structural complexity on the critical region, but total reading is a measure more related to integrative later processes during comprehension. An interesting finding in this context is the number interference effect in first fixation duration and first-pass time on the spillover region which occurred earlier than the syntactic interference effect. Van Dyke reported an effect of animacy in first-pass and regression-path time on the spillover region, but not in first fixation duration measure as was observed in Experiment 5 with number interference.

On the one hand, Experiment 5 reported an early number interference effect and Van Dyke (2007), on the other hand, reported a late semantic interference effect. This suggests that the interference effect caused by matching number nouns is different from and occurs earlier than semantic interference.

There is one crucial difference in the interest areas between Experiment 5 and the Van Dyke (2007) study. The critical region in Van Dyke (2007) is the main verb (*moaned*) while the critical region in Experiment 5 is the auxiliary (*has been*) that precedes the main verb (*awarded*). The auxiliary was defined as the critical region because *has been* agrees in number with the singular subject, whereas *moaned* (which was the critical region in Van Dyke) can plausibly only take an animate subject. In Experiment 5 the whole verb phrase *has been awarded* was split into the critical (*has been*) and the spillover region (*awarded*). This split might be an explanation why only the total reading time measure showed an effect at the critical region in Experiment 5. Number agreement has to be established at the critical region (*has been*), the whole verb phrase will only be fully integrated at the main lexical verb *awarded* and therefore the spillover region. All other effects (number and syntactic complexity) were observed at the spillover region or on the final region.

Number interference was observed in earlier measures (first fixation duration, first-pass time) and the syntactic interference effect in later reading time measures (regression-path, total reading time). This suggests that number interference either occurred earlier or at least not later than the syntactic complexity effect. The timing of the number interference and the syntactic interference effect differ from the timing of the semantic and the syntactic interference effect reported by Van Dyke (2007). Van Dyke (2007) argued that the syntactic interference effect should occur early. The different kind of information that number and animacy provide might also be involved in different kind of processes. The information about the animacy of noun phrases seem to be part of later semantic processes. Whereas the number information of noun phrases also affects the marking of the verb. According to the marking and morphing model (Bock et al., 2004; Eberhard et al., 2005) number agreement between a subject and a verb has to be established before syntactic structure building. Therefore, agreement processes operate more rapidly and number interference occurs before syntactic interference during sentence processing.

To summarise, effects of number interference occur during sentence processing. These effects are caused by a number congruent local noun phrase when the original subject noun had enough time to decay. When the subject had enough time to decay, number interference effects from a local noun phrase occur early and before the interference effect due to verb subcategorization cue overlap.

9 Experiment 6

9.1 Introduction to Experiment 6

Bock and Miller (1991) describe the so-called *asymmetry error* during the production of subject-verb agreement. The authors reported a common mistake in speech production. The verb doesn't agree with its subject, but with a noun phrase that is between the subject and the verb: *The bridge to the islands were crowded.* (Bock & Miller, 1991, p. 63). The verb *were* and its local noun *islands* agreed in number, indicating that the speaker misinterpreted *the islands* as the subject of the verb *were*. This is an asymmetric effect since the production error occurs most often when the local noun is plural while the actual subject noun is singular. This error occurs significantly less often when the local noun is singular while the actual subject is plural.

Arguing that production and comprehension processes are similar, Wagers et al. (2009) investigated the number attraction effect in comprehension using the self-paced reading paradigm. Wagers et al. reported that number attraction affected the processing of ungrammatical sentences (*The key to the cells (unsurprisingly) were rusty from many years of disuse.* (Wagers et al., 2009, p. 221)): the disruption of processing an ungrammatical sentence was reduced when there was a local plural noun (*cells*) before the main plural verb (*were*) (while the actual subject *key* was singular).

However, number attraction did not affect the processing of the grammatical sentences tested in Wagers et al. (2009). Wagers et al. contrasted grammatical and ungrammatical relative clause (*The musician who the reviewer praise(s) so highly will probably win a Grammy.* (Wagers et al., 2009, p. 213)) and prepositional phrase structures (*The key to the cells (unsurprisingly) were / was rusty from many years of disuse.* (Wagers et al., 2009, p. 221)). Their findings suggest that attraction does not affect the comprehension of grammatical relative clause structures and sentences with prepositional phrases. However, what about other structures like garden path sentences? If number attraction is a small effect in comprehension, other effects, like similarity based interference, might be stronger in the prepositional phrase and relative clause conditions. However, number attraction might still affect other structures like the processing of garden path sentences. Wagers et al. (2009) found attraction effects during the processing of ungrammatical sentences. This suggests that attraction might affect later checking processes when readers try to process an ungrammatical structure. Therefore, checking may be particularly common when a sentence is misinterpreted, like garden path sentences.

Examples (1a, 1b) contain a local ambiguity at *cousin of the farmer*. The verb (*answered*) might either be used transitively, making *the cousin of the farmer* the object of *answered* or intransitively without an object, making *the cousin of the farmer* the subject of the main clause. This ambiguity is resolved at the verb *has to*. In case readers adopted the transitive interpretation while reading the sentence, the integration of *has to* poses a challenge forcing the reader to search for the point of the initial misinterpretation and reanalyse the structure.

1. (a) **ambiguous / singular NP2**
   After Virginia answered the cousin of the farmer has to think it all over again.

   (b) **ambiguous / plural NP2**
   After Virginia answered the cousin of the farmers has to think it

all over again.

(c) **unambiguous / singular NP2**
After Virginia answered, the cousin of the farmer has to think it all over again.

(d) **unambiguous / plural NP2**
After Virginia answered, the cousin of the farmers has to think it all over again.

Similarity based interference and accounts of number attraction make different predictions about how reanalysis might be affected. In Example (1) the two noun phrases before the verb vary in their number information. The subject of the prepositional phrase (*the cousin*) is singular in all the conditions. However, the second noun phrase within the prepositional clause is either singular (*farmer* in 1a, 1c) or plural (*farmers* in 1b, 1d). In addition, ambiguous conditions (1a,1b) were compared with unambiguous (1c,1d). By inserting a comma after the ambiguous verb, *answered* can only be interpreted as an intransitive verb that does not take an object. Therefore, readers do not misinterpret *the cousin of the farmer* as the object of *answered* in (1c) and (1d). According to number attraction, the integration of *has to* should be harder after the plural local *farmers* in (1b) and (1d) since the number information of the local noun (*farmers*) does not match the number information at the verb. In addition, previous studies have also shown that the effects caused by number attraction in comprehension are unclear. Nicol et al. (1997), for example, has shown number attraction in comprehension in offline measures. The effects presented by Pearlmutter et al. (1999) might be a spillover effect from plural noun phrases and Pearlmutter (2000) reported attraction from a singular number attractor and not from a plural number attractor, which is not in agreement with production research. In addition, Wagers et al. (2009) have shown number attraction effects for ungrammatical sentences.

Similarity-based interference, on the other hand, predicts that *has to* should be harder after the local singular *farmer* in (1a) and (1c). This is due to the similarity of the interfering singular noun with the subject noun phrase: both the local *farmer* and the subject *cousin* are singular. However, the distance between the verb and the subject is very small and therefore similarity based interference should not be strong. Therefore, similarity based interference and number attraction effects make opposite predictions about reading time differences at the verb *has to* and both attraction and interference are predicted to be weak effects in Experiment 6.

9.2 Method

9.2.1 Participants

Experiment 6 had forty participants from the University of Dundee. Participants were non-dyslexic English native speakers and were naïve about the experiment hypothesis. Participants agreed to take part in the experiment and allowed their data to be used for analysis. In exchange they received course credits or five pounds for their participation. They were treated according to the ethical standards of the University of Dundee and the study was approved by the ethics committee of Dundee University.

9.2.2 Materials

Forty experimental sentences were created for Experiment 6. Condition (1a and 1b) were strong garden-path sentences. Ambiguity was induced by using verbs that are commonly followed by an object, which means they are preferentially transitive. However, the verb used here can also be used without an object, which means that they can be transitive or intransitive, but with a transitive preference. The sentence started with a common name (*Virginia*), followed by a transitive/intransitive verb (*answered*) and a prepositional phrase (*the cousin of the farmer*). Participants were expected to initially interpret these verbs transitively and attach the first noun phrase of the prepositional phrase as the object of the verb. The prepositional phrase (*the cousin of the farmer*) is a long noun phrase in object position, this was followed by a verb phrase that disambiguated the previous structure and readers will have to reanalyse the sentence if they initially adopted the transitive interpretation of *answered*. Since the noun phrase in object position

was long (the prepositional phrase *the cousin of the farmer*), the disambiguation of the verb was delayed and was expected to cause a strong garden-path effect.
Conditions (1c and 1d) displayed a comma after the verb. Thus, the verb could only be integrated. The comma served as a disambiguation of the verb interpretation. With *answered* as an intransitive verb, the following object (*the cousin*) should not be interpreted as the object of the verb (*answered*).

Conditions (1a and 1c) contain two singular nouns (*cousin, farmer*) in the complex noun phrase after the ambiguous verb. While for conditions (1b and 1d) the second noun phrase is plural (*farmers*) and the first noun phrase is singular (*cousin*).

Table 43 shows the areas of interest that were analysed in Experiment 6. The critical region contains the verb *has to*, this verb disambiguates the previously seen sentence structure and therefore an effect of ambiguity is expected to occur at this verb. In addition, *has to* agrees with the subject *cousin* in number and effects of either similarity based interference or number attraction should occur at the critical region. Next is the spillover region *think it*. It consists of the following lexical verb after *has to*, in case this verb is not at least 7 characters long, a following word will be added to the spillover region. Some processes will only finish after the critical word has been read and therefore effects of these processes might be observed at the following word. These are spillover effects and the region is therefore called spillover region. The final region consists of the rest of the sentence after the spillover region. Here, final sentence wrap-up processes are expected to be observed.

Table 43: Areas of interest for Experiment 6

critical	**spillover**	**final**
has to	think it	all over again.

After each sentence a comprehension question was presented. Table 44 shows the different comprehension questions for a sample sentence. These comprehension questions asked for different information in the sentence. The questions were equally distributed over the presented sentences, with twenty questions that required a "yes" response and twenty questions that required a "no" response.

Table 44: Comprehension questions - Experiment 6

After Virginia answered the cousin of the farmers has to think it all over again.

Yes-questions	**No-questions**
(a) Did Virginia answer?	(a) Did the farmer answer?
(b) Did the cousin have to think it all over again?	(b) Did Virginia have to think it all over again?

9.2.3 Design

Experiment 6 had a 2×2 within-subjects design with forty critical sentences. The first variable was ambiguity: sentences were ambiguous (conditions (1a) and (1b)) or unambiguous (conditions (1c) and (1d)). As a second variable, the number feature of the local noun (*farmer(s)*) was manipulated. The local noun was either in singular (same number as the verb) or in plural (different number from the verb).

As was done in previous experiments, eight lists with all items were created. Eight lists were chosen due to the nature of an unrelated experiment whose sentences served as fillers for this experiment. Each list contained forty critical items with four conditions, thus they were ten items for each condition within a list. While the overall order of the list was randomised, the order was the same between the eight different lists. Five participants were randomly chosen for each list. In addition to the critical items, 77 filler sentences were used in this experiment. All sentences, critical and filler, were followed by a Yes/No comprehension question.

9.2.4 Apparatus and procedure

The apparatus and the procedure for the sixth eye-tracking experiment were identical to the previous eye-tracking experiments.

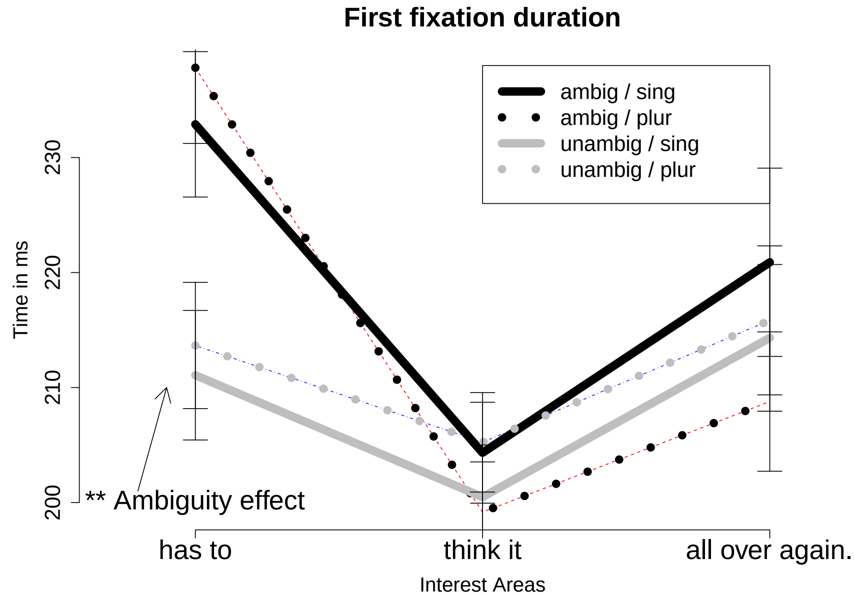
9.3 Results

Four different measures were analysed for the sixth eye-tracking experiment: *first fixation duration*, *first-pass time*, *regression-path time* and *total reading time*. These measures were defined in results section of Experiment 1. In addition to the reading time measures, comprehension question errors were analysed in Experiment 6.

Eight additional participants had to be excluded from the data analysis because their error rate in answering the comprehension questions correctly, exceeded 25%. The data of forty participants were used for the analysis.

Figures 23, 24, 25 and 26 below show the different reading time measures for the three regions: critical, spillover and wrap-up. Figure 23 shows first fixation duration on the different regions, Figure 24 first-pass time, Figure 25 regression-path time and Figure 26 illustrates the total reading time. In addition, Table 49 gives the means of the comprehension question errors of Experiment 6. Tables 45 (first fixation duration), 46 (first-pass time), 47 (regression-path time), 48 (total reading time) and 50 (comprehension question error) show the F- and p-values of the analyses of variance of Experiment 6.

As no effect is expected to occur before the critical region, this region is not displayed in the figures. For the data analysis both analyses of variance with subjects (F1) and items (F2) as a random variable were conducted. Ambiguity (ambiguous vs unambiguous levels) and number congruency (number congruent vs number incongruent levels) were treated as within subject and within item fixed variables. Subject group was fixed between subject variables in the by-subject analyses and item group between item variable in the by-item analyses. The analysis was done on subject means per condition (F1) and item means per condition (F2).



has to	think it	all over again.
critical	spillover	final

conditions	critical	spillover	final
ambiguous / singular	232.89	204.33	220.89
ambiguous / plural	237.81	199.17	208.78
unambiguous / singular	211.07	200.48	214.32
unambiguous / plural	213.66	205.24	215.84

Figure 23: First fixation duration means in ms - Experiment 6

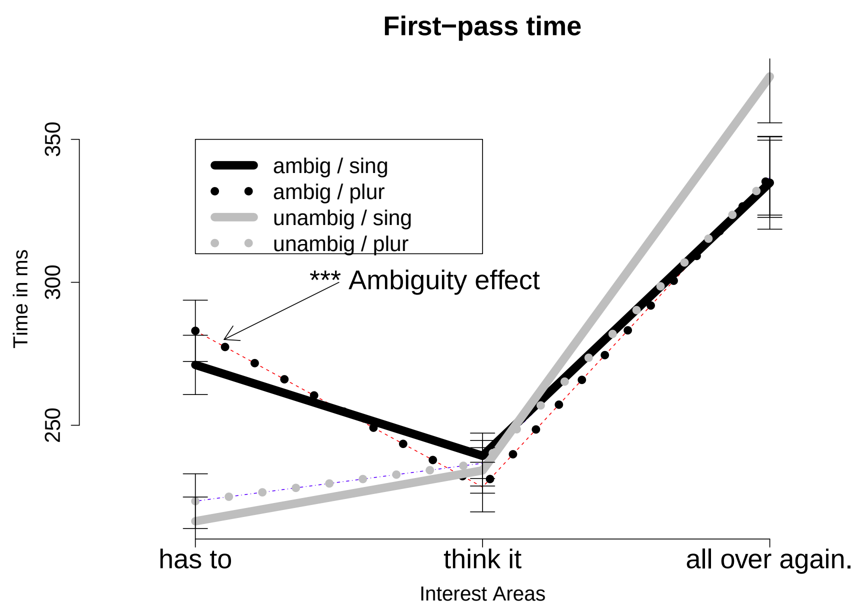
9.3.1 Analysis of the critical region: `has to`

Analyses of variance showed a main effect of ambiguity for first fixation duration: $F1(1,36) = 8.93$, $p < .01$; $F2(1,36) = 11.11$, $p < .005$. The ambiguous conditions were harder to process than the unambiguous conditions.

A significant effect of ambiguity was also observed for first-pass time at the critical region: $F1(1,36) = 23.97$, $p < .001$; $F2(1,36) = 15.64$, $p < .001$. Means for the ambiguous conditions were longer than for the disambiguated conditions. There was an effect of number congruency for first-pass time that was significant by items: $F2(1,36) = 4.38$, $p < .05$; but not significant by

Table 45: F and p values of first fixation duration - Experiment 6

F1/F2	**critical**	**spillover**	**final**
Number of NP2			
F1	<1	<1	<1
p	.40	.99	.92
F2	<1	<1	<1
p	.43	.78	.39
Ambiguity			
F1	**8.93**	<1	<1
p	<**.01**	.49	.48
F2	**11.11**	<1	<1
p	**.002**	.40	.69
Interaction:			
Number of NP2 × *Ambiguity*			
F1	<1	<1	<1
p	.86	.69	.36
F2	<1	<1	<1
p	.86	.87	.47



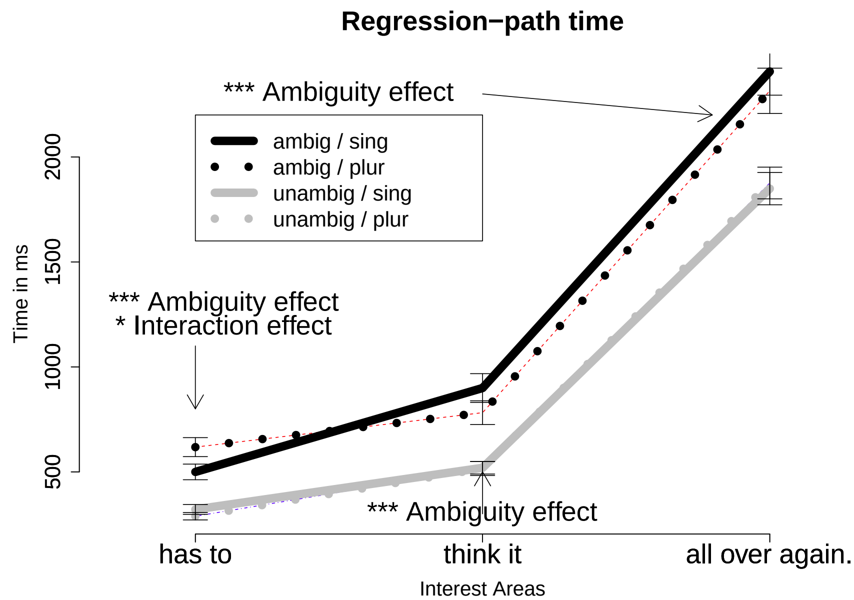
has to	think it	all over again.
critical	spillover	final

conditions	critical	spillover	final
ambiguous / singular	271.12	239.31	334.82
ambiguous / plural	283.03	228.39	336.80
unambiguous / singular	216.44	234.21	371.99
unambiguous / plural	223.46	236.72	336.61

Figure 24: First-pass time means in ms - Experiment 6

Table 46: F and p values of first-pass time - Experiment 6

F1/F2	**critical**	**spillover**	**final**
Number of NP2			
F1	2.05	<1	1.14
p	.16	.57	.29
F2	**4.38**	<1	1.20
p	**.04**	.74	.28
Ambiguity			
F1	**23.97**	<1	**5.02**
p	<**.001**	.72	**.03**
F2	**15.64**	<1	**3.38**
p	<**.001**	.80	**.07**
Interaction: Number of NP2 × Ambiguity			
F1	<.005	<1	**4.17**
p	.96	.88	**.05**
F2	<1	<1	1.86
p	.54	.75	.18



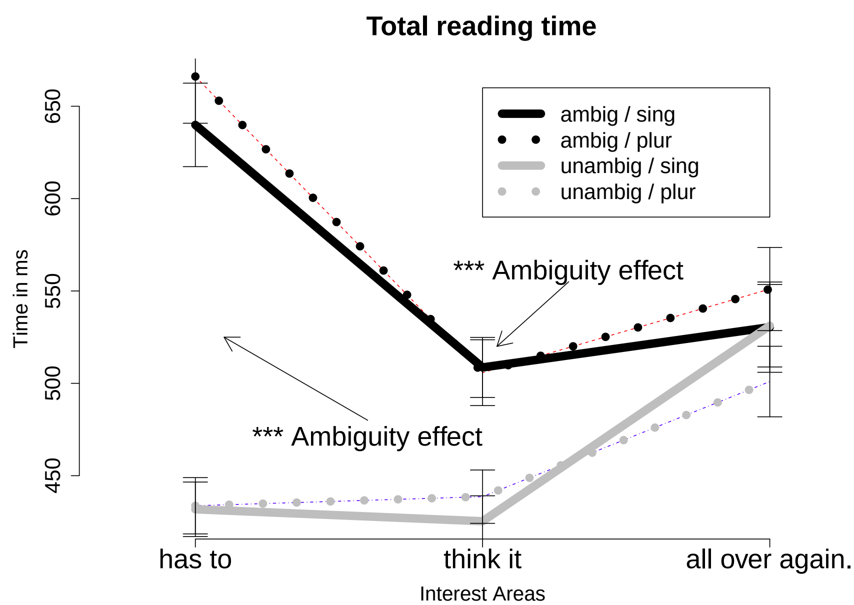
has to	think it	all over again.
critical	spillover	final

	critical	**spillover**	**final**
ambiguous / singular	499.72	899.27	2407.05
ambiguous / plural	617.83	781.94	2315.02
unambiguous / singular	321.02	519.36	1849.18
unambiguous / plural	288.65	516.11	1875.93

Figure 25: Regression-path time means in ms - Experiment 6

Table 47: F and p values of regression-path time - Experiment 6

F1/F2	**critical**	**spillover**	**final**
Number of NP2			
F1	2.46	1.00	<1
p	.13	.32	.60
F2	2.26	<1	<1
p	.14	.41	.90
Ambiguity			
F1	**25.53**	**33.85**	**19.27**
p	**<.001**	**<.001**	**<.001**
F2	**43.35**	**52.74**	**32.26**
p	**<.001**	**<.001**	**<.001**
Interaction: Number of NP2 × Ambiguity			
F1	**4.87**	<1	<1
p	**.03**	.44	.51
F2	**5.03**	<1	<1
p	**.03**	.56	.64
Simple effects ambiguous			
F1	**5.26**	-	-
p	**.03**	-	-
F2	**5.67**	-	-
p	**.02**	-	-
Simple effects unambiguous			
F1	<1	-	-
p	.66	-	-
F2	<1	-	-
p	.59	-	-



has to	think it	all over again.
critical	spillover	final

Conditions	critical	spillover	final
ambiguous / singular	639.90	508.62	530.41
ambiguous / plural	666.12	505.77	551.05
unambiguous / singular	431.79	425.34	531.18
unambiguous / plural	433.73	438.64	500.97

Figure 26: Total reading time means in ms - Experiment 6

Table 48: F and p values of total reading time - Experiment 6

F1/F2	**ciritical**	**spillover**	**final**
Number of NP2			
F1	1.33	<1	<1
p	.26	.66	.95
F2	1.00	<1	<1
p	.32	.52	.97
Ambiguity			
F1	**62.75**	**27.79**	0.61
p	**<.001**	**<.001**	.44
F2	**80.99**	**22.35**	2.44
p	**<.001**	**<.001**	.13
Interaction: Number of NP2 × Ambiguity			
F1	<1	<1	**4.26**
p	.44	.71	**.05**
F2	<1	<1	**2.86**
p	.45	.95	**.10**
Simple effects ambiguous			
F1	-	-	2.32
p	-	-	.14
F2	-	-	1.07
p	-	-	.31
Simple effect unambiguous			
F1	-	-	2.46
p	-	-	.13
F2	-	-	1.48
p	-	-	.23

Table 49: Means of comprehension question errors in Experiment 6

ambiguous - singular	**ambiguous - plural**	**unambig - singular**	**unambig - plural**
0.20	0.15	0.13	0.14

Table 50: F and p-values of comprehension question errors in Experiment 6

F / p	Ambiguity	Nr of NP2	interaction Ambiguity × Nr of NP2
F1(1,36)	**8.64**	1.69	2.45
p	**<.01**	.20	.13
F2(1,36)	**5.16**	1.49	**4.06**
p	**.03**	.23	**.05**

subjects. The conditions with number incongruent noun phrases were read more slowly than those number congruent noun phrases.

The analyses also showed a main ambiguity effect for regression path duration: $F1(1,36) = 25.53$, $p < .001$; $F2(1,36) = 43.35$, $p < .001$. The means of the ambiguous conditions were significantly longer than the means of the unambiguous conditions. This effect of ambiguity was modulated by an interaction between ambiguity and number of NP2 in regression path time: $F1(1,36) = 4.87$, $p < .05$; $F2(1,36) = 5.03$, $p < .05$. Simple effect analyses showed that an effect of number congruency for the ambiguous sentences: $F1(1,36) = 5.26$, $p < .05$; $F2(1,36) = 5.67$, $p < .05$. Ambiguous conditions with a plural second noun phrase had longer reading times than ambiguous conditions with a singular second noun phrase. The analysis for the unambiguous conditions did not show an effect (Fs < 1).

The analyses of total reading time at the critical region showed a main effect of ambiguity: $F1(1,36) = 62.75$, $p < .001$; $F2(1,36) = 80.99$, $p < .001$. The ambiguous conditions were more difficult than the unambiguous conditions at the critical region in total reading time.

There were no other main effects or interactions in the other measures at the critical region.

9.3.2 Analysis of the spillover region: `think it`

The ANOVAs showed a main effect of ambiguity for regression path time with $F1(1,36) = 33.85$, $p < .001$; and $F2(1,36) = 52.74$, $p < .001$. Conditions with an ambiguity were read more slowly at this region than the unambiguous conditions.

Furthermore, there was a main effect of ambiguity for the total reading time measure: $F1(1,36) = 27.79$, $p < .001$; and $F2(1,36) = 22.35$, $p < .001$. The means for the ambiguous conditions were longer than those for the unambiguous conditions.

There were no other main effects or interactions in any of the other measures at the spillover region.

9.3.3 Analysis of the final region: `all over again`

The analyses of variance of the reading times showed a main effect of ambiguity for first-pass time that was significant by subjects: $F1(1,36) = 5.02$, $p < .05$; and marginally significant by items $F2(1,36) = 3.38$, $p = .07$. The unambiguous conditions were read more slowly at this position than the ambiguous conditions. The interaction of ambiguity and number congruency was significant by subjects $F1(1,36) = 4.17$, $p < .05$; though the analysis by items was not significant.

In addition, the analysis showed a significant main effect of ambiguity for regression path time at the final region: $F1(1,36) = 19.27$, $p < .001$; and $F2(1,36) = 32.26$, $p < .001$. Ambiguous conditions were read more slowly than the unambiguous conditions.

The analyses of variance for total reading time at the final region showed an interaction effect between ambiguity $\times$ number congruency that was significant by subjects $F1(1,36) = 4.26$, $p < .05$; the difference was marginally significant by items $F2(1,36) = 2.86$, $p = .099$. A simple effects analyses did not show any significant differences of number congruency in the ambiguous and also not in the unambiguous conditions (biggest $Fs = 2.46$, smallest $p = 0.13$).

There were no other main effects or interactions at the final region in any of the other measures.

9.3.4 Analysis of the comprehension question errors

The analysis showed a main effect of ambiguity in the comprehension question errors by subjects $F1(1,36) = 8.64$, $p < .01$ and by items $F2(1,36) = 5.16$,

$p < .05$. Ambiguous conditions had a higher error rate than unambiguous conditions. There was no effect of the number of the noun phrase in the errors of the comprehension questions.

9.4 Discussion of Experiment 6

The reading times of Experiment 6 showed clear effects of ambiguity resolution at the critical region (*has to*) in first fixation duration, in first-pass time, in regression-path time and in total reading time. In addition, there was also an ambiguity effect at the spillover region (*think it*) in regression path time and in total reading time. Ambiguity also had an effect at the final region (*all over again*) in regression-path time and in total reading time. In all these measures and interest areas the ambiguous condition had longer reading times than the unambiguous conditions. In addition to the ambiguity effect in the reading times, there was also an ambiguity effect in the comprehension errors. Ambiguous conditions had a higher error rate than the unambiguous conditions. The effect of ambiguity was expected. However, similarity-based interference and number attraction made different predictions about the effect of the number of the local noun phrase. That is why the interaction reported in regression-path is the most relevant finding in this experiment. There was a significant interaction between ambiguity and number congruency at the critical region (*has to*) in regression-path time. In the ambiguous conditions, there were significantly longer reading times at *has to* when the local noun phrase was plural than when the local noun phrase was singular. The reading times for the critical region did no differ between the local singular noun and the local plural noun in the unambiguous conditions. This interaction showed an effect of number attraction: a local plural noun made the reanalysis process more difficult than a local singular noun phrase.

These findings are more in agreement with number attraction and challenging for a similarity based interference account. The absence of a similarity-based interference effect might be due to the small distance between the verb *has to* and its subject *the cousin*. There was only one item (*farmer*) between the subject and the verb. Thus, *the farmer* did not reduce the activation of the subject *cousin* enough to cause an interference effect at the verb.

The interaction between number and ambiguity is actually consistent with the number attraction findings reported by Wagers et al. (2009). Assuming readers initially interpret *answered* as a transitive verb and integrate *the cousin of the farmer* as its object, readers will experience a problem when they encounter *has to*. With the interpretation of *the cousin of the farmer* as the object of *answered* the integration of *has to* will render the sentence ungrammatical. Thus, before the reanalysis, readers are faced with an ungrammatical sentence like in Wagers et al. (2009). Wagers et al. (2009) reported that number attraction affected the reading times of ungrammatical sentences. Assuming readers attempt to recover from ungrammatical structures and number attraction affects late checking processes

While Wagers et al. used globally ungrammatical sentences, readers can resolve the ungrammaticality in Experiment 6 by reanalysing the structure they build so far. Thus, number attraction in Experiment 6 might have been part of later processes of structural reanalysis. The fact that there was no number attraction effect in the unambiguous conditions further supports this hypothesis. There are no processes of reanalysis in the unambiguous conditions, readers do not have to recover from an initial misinterpretation of the sentence structure. Thus, number attraction does not seem to affect processes of initial structure building. Number attraction interacts with processes of recovery and reanalysis late during sentence processing.

10 General Discussion

10.1 Discussion of the experiments

The introduction of this thesis described memory effects in sentence comprehension processes. The main argument of the similarity based interference account described how effects of comprehension difficulty arise due to interference of working memory processes. For example, during the reading of a sentence, words need to be temporarily stored in memory in order to integrate them later. Example sentence (1) contains an object relative clause and in order to integrate the verb *helps*, *the banker* needs to be retrieved from memory to take the object role in the embedded clause and *the accountant* needs to be retrieved to take the subject role.

1. **object relative**
   The banker that the accountant helps counted the money.

When the noun phrases *banker* and *accountant* are in memory and are too similar to each other it becomes difficult to identify the target subject (*accountant*) and the target object (*banker*) of the relative clause. Thus, the integration of the verb will become difficult and therefore memory processes affect the comprehension of the sentence.

The retrieval cue based account by Van Dyke and Lewis (2003) not only provides a detailed account of similarity between items, it also makes predictions about when interference effects should occur. Van Dyke and Lewis described how retrieval cues guide retrieval processes (e.g., cues for animacy, gender and number): one of these retrieval cues is number information. According to Van Dyke and Lewis two number congruent noun phrases (both noun phrases are singular or both are plural) in memory should interfere more with each other than two noun phrases that are number incongruent (one noun phrase is singular and the other is plural). In addition, Van Dyke and Lewis predicted that object relative clauses should be harder than subject relative clauses because, in object-relatives there are two noun phrases in memory when the embedded verb needs to be integrated, whereas there is only one noun phrase in memory at the embedded verb of a subject relative clause. This difficulty associated with object relatives should be even more pronounced when the noun phrases in memory are more similar to each other (e.g., similar because both noun phrases have the same number).

Experiments 1 and 2 tested the predictions that (1.) object relatives are harder than subject relatives and (2.) object relatives with similar noun phrases in memory should be harder than object relatives with dissimilar noun phrases in memory, manipulating the number information of the noun phrases in memory. Two eye-tracking experiments compared object-relative clauses with subject-relative clauses (2). The two noun phrases in the relative clause were either number congruent (both singular or both plural) or number incongruent (one singular and the other plural). According to similarity based interference, the object-relative condition (2b) should be more difficult than the subject-relative condition (2a) since the object relative has one interfering item (*accountant(s)*) between the subject (*banker(s)*) and its verb (*help(s)*). In addition, the retrieval cue parsing account predicts that when this interfering item is similar to the subject the difficulty associated with verb integration should be more pronounced. Therefore, the object-relative condition should elicit longer reading times when the two noun phrases are number congruent than when they are number incongruent.

2. (a) **subject relative**
   The banker(s) that | help(s) the accountant(s) | counted | the money (| several times).

   (b) **object relative**
   The banker(s) that | the accountant(s) help(s) | counted | the money (| several times).

Experiment 1 showed that object relatives were harder than subject relatives, which is in line with previous studies (Gibson, 1998; Gordon et al., 2001; Hale, 2006; King & Just, 1991; Lewis, 1996; MacWhinney & Pleh, 1988). However, contrary to the predictions of similarity-based interference, reading times in Experiment 1 showed that conditions with incongruent noun phrases had longer reading times than conditions with congruent noun phrases in regression-path time at *counted*. There was no other effect of number congruency in Experiment 1. These findings are not in agreement with the predictions of similarity-based interference. On the contrary, they were even in the opposite direction. This effect might be an indication of priming of number information. The number information of the first noun phrase might have primed the number of the second noun phrase. Therefore, longer reading times were observed when the number of the two noun phrases was incongruent.

There are two possible reasons for the absence of an interference effect in Experiment 1. First, there was only one interfering item in the relative clause. Due to the relatively short distance between the subject and its verb, the activation of the subject might not have decayed much and is therefore easily retrieved from memory. As a result, interference might only be a weak effect in single centre-embedded sentences like in Experiment 1.

A second reason is that interference might not be part of the early integrative syntactic processing of object relatives. Sturt (2003) found that inaccessible antecedents in anaphor resolution don't affect initial processing but can affect later integrative processing. Sturt argued that this effect might not be part of early anaphor resolution processes, but rather some later checking procedures that occur with recovery and final sentence wrap-up strategies. Similarly, the effect of number interference might also not be part of early syntactic processes, but occur later. However, the region after the critical relative clause was very long in Experiment 1. If there really was a number interference effect and it didn't occur together with the early syntactic processes, it might have been spread out over the long final region making it too weak to detect. In order to test this, Experiment 2 was conducted that used a shorter final region, which might result in a more condensed, stronger effect.

If number interference is part of final integrative processes and indeed was spread out over the long final region (that consisted of several regions), it is more likely that a number interference effect will be observed in Experiment 2 when the final region has been shortened.

Reading times in Experiment 2 confirmed the findings of the relative clause effect of Experiment 1. Object-relatives had longer reading times than subject-relatives. More interestingly, first-pass time showed an interaction at the final wrap-up region (*the money*) of the sentence in Experiment 2: object relative conditions with nouns congruent in number had longer reading times than those with incongruent noun phrases, while the two subject-relative conditions (number congruent and number incongruent) did not show any difference.

While the interaction between relative clause type and number congruency was predicted, the delay of this effect to the last region is not in agreement with the similarity based interference approach by Van Dyke and Lewis

(2003). The effect of number interference should have been observed together with the relative clause effect. However, while the relative clause effect was strong and found in several reading times measures (early and late measures) in both Experiment 1 and Experiment 2, the number interference effect was observed late at the sentence wrap-up region. Thus, these findings are similar to the results presented by Sturt (2003) about delayed anaphor resolution due to inaccessible antecedents. The number interference effect seems to occur together with the sentence wrap-up processes that occur at the end of a sentence as part of a checking procedure.

This has implications for the similarity-based interference account of Van Dyke and Lewis (2003) and Lewis and Vasishth (2005). The results of Experiment 1 and Experiment 2 indicate that number interference is a weak effect. Number interference did not affect the reading times of object relatives in Experiment 1. However, The interaction showed that number interference affected object-relative clauses in Experiment 2. While the relative clause effect was observed early in Experiment 1 and in Experiment 2, number interference affected only the reading times at the final sentence wrap-up region in Experiment 2. This delay of number interference in comparison to the relative clause effect is not consistent with Van Dyke and Lewis, who claimed that interference difficulty should be observed at the verb when the two items need to be retrieved. Thus, according to Van Dyke and Lewis the relative clause difficulty and the number interference effect should have occurred simultaneously at verb integration.

Therefore, the results suggest that interference is a weak effect that does not occur during structure building. However there was only one interfering item between the subject and the verb in the object relative conditions, the separation between the verb and its subject might not have been big enough to cause a strong decay of the subject's activation. Therefore, the object causes only weak interference, which was only observed in Experiment 2. In Experiment 1, however, this effect was spread over the long region, that followed the relative clause and the interference effect could therefore not be detected. In addition to being weak, the number interference effect occurred later than the relative clause effect. This would suggest that the relative clause effect might not be due to memory interference after all, as was suggested by Van Dyke and Lewis (2003); Lewis (1996) and Lewis and Vasishth (2005).

The findings of both Experiments are more in agreement with theories that assume that processing difficulty with object relatives is not due to interference. Examples for such theories are the locality account (Gibson, 1998), models of expectation (Hale, 2006) and surprisal (Levy, 2007). Given the findings in Experiments 1 and 2, memory interference is a late effect that occurs together with checking processes at the end of the sentence. This motivated a research question for the following experiments: is the time-course of similarity based interference similar if there was a greater distance between the subject and its verb? With a larger interfering region, the activation of the subject has more time to decay and thus the subject should be harder to retrieve from memory. With more than one similar interfering item in memory, the number interference effect should be stronger. But the question is whether it would still be a late effect.

Experiments 1 and 2 investigated effects of similarity based interference manipulating the number cue of the noun phrases that need to be stored in memory. The number information of noun phrases, however, also plays a big part in agreement processes in sentence processing. Agreement in sentences highlights what items in a sentence belong together and in particular number agreement signals the connection between a subject and its verb in a sentence. Thus, number information of noun phrases can cause similarity based interference processes, while they can also signal agreement between a subject and a verb.

One potential explanation for the weak number interference effect in Experiment 1 + 2 is that the activation of the original subject did not decay enough for the object to cause an early interference effect at the verb. The interference effect might be observed earlier when the subject had enough time to decay.

However, number information of noun phrases is not only important for retrieval, but also for agreement processes: e.g. in *The teacher says* … the number marking of the verb (*says*$_{sing}$) has to agree with the number of its subject (*teacher*$_{sing}$).

Wagers et al. (2009) have shown that agreement effects like number attraction errors, which have originally been reported in production studies (Bock & Miller, 1991; Bock & Cutting, 1992; Pearlmutter, 2000), also affect the comprehension of ungrammatical sentences. Attraction errors occur often during language production. They are most common when a sentence contains a prepositional phrase like *The key to the cabinets*. The following verb sometimes agrees with the local plural noun *keys* instead of with its actual subject noun *key* resulting in the ungrammatical utterance **The key to the cabinets are on the table*. As a consequence, the resulting sentence is ungrammatical. While these number attraction effects have been extensively researched in production, their impact on comprehension is less clear. Wagers et al. reported that number attraction affected the processing of ungrammatical sentences: ungrammatical sentences with a local number attractor before the verb had faster reading times than ungrammatical sentences without a local number attractor before the verb.

If number attraction indeed affects comprehension of grammatical sentences, then number attraction makes different predictions from the number interference account. Number interference predicts longer reading times when the noun phrases in memory are number congruent than when they are incongruent. According to number attraction, a local number attractor (a preceding plural noun while the verb is in singular) should disrupt agreement processes at the following verb. Therefore, number attraction predicts that a prepositional phrase before the verb with a local plural noun (a local noun is that noun immediately preceding the verb) and a singular subject noun (the number incongruent condition) should cause longer reading times at the following verb than a preceding prepositional phrase with a local singular noun and a singular subject noun.

Experiments 3 and 4 were designed to test whether the addition of another noun phrase between subject and verb elicits a stronger interference effect. Participants read sentences like example (3). According to the number interference account, there should be longer reading times when either the local noun phrase (NP3 *politician* in 3a and 3b) or the second noun phrase (NP2 *assistant* in 3a and 3c) was in singular than when they are in plural. If number attraction affects comprehension there should be processing disruption when the main singular verb is preceded by a plural noun phrase. (In production, Number attraction errors were more likely to occur when a singular subject noun is followed by a plural noun in a prepositional phrase than when a plural subject is followed by a singular noun in a prepositional phrase. Thus, while number attraction can occur for both scenarios in comprehension, it should be more likely to occur with a singular subject and a second plural noun.)

The number information of the local plural NP3 passes to the singular verb and their number mismatch will cause processing disruption. Thus, there should be longer reading times when the main verb *was* is either preceded by the plural NP3 *politicians* in (3c) and in (3d) or by the plural NP2 *assistants* in (3b) and in (3d) in comparison to when the main verb is either preceded by a singular NP3 *politician* in (3a) and (3b) or by a singular NP2 *assistant* in (3a) and (3c).

3. (a) **second singular / local singular**
   The chauffeur | who greeted | the assistant of the politician | was at | the station's | taxi rank.

   (b) **second plural / local singular**
   The chauffeur | who greeted | the assistants of the politician | was at | the station's | taxi rank.

   (c) **second singular / local plural**
   The chauffeur | who greeted | the assistant of the politicians | was at | the station's | taxi rank.

   (d) **second plural / local plural**
   The chauffeur | who greeted | the assistants of the politicians | was at | the station's | taxi rank.

The findings of Experiment 3 showed longer reading times when a singular NP3 (*politician*) directly preceded the critical main verb (*was*) than when it was preceded by a plural NP3. The number of the NP2 *assistant* did not have an effect on the reading times in Experiment 3.

In sum, a singular NP3 that directly preceded the main verb caused longer reading times than a plural NP3 directly preceding the verb. This finding is in agreement with the predictions made by the retrieval cue parsing account by Van Dyke and Lewis (2003) and Lewis and Vasishth (2005). In order to integrate the main verb *was* into the sentence, the singular subject *chauffeur* needs to be retrieved from memory. However, the presence of the singular *politician* in memory interferes with the search for the target subject. Interestingly, there was no interference effect from the second noun phrase (*assistant(s)*). However, this is in agreement with the similarity based parsing account, which predicts that the activation of memory traces decays over time and therefore the NP2 becomes unavailable. Because the activation of the second noun phrase decays over time (the second noun phrase *assistant(s)* is more distant to the main verb *was* than the local / third noun phrase *politician(s)*), its number information is unavailable at the verb and therefore does not interfere with the retrieval of the target subject (*chauffeur*).

The reading time measures analysed in Experiment 3 didn't show any sign of number attraction from NP2 or NP3. There are three potential explanations for this. First, a large proportion of the embedded verbs that were used in Experiment 3 resulted in temporary ambiguity (e.g. the embedded verb *advised* can occur with a sentence complement, which might potentially cause readers to interpret the following complex noun phrase as the subject of a sentential complement, e.g. *The janitor who advised (that) the apprentice of the carpenter was at the station's taxi rank (left)*). While this interpretation will have to be corrected later when the readers reach the end of the sentence, it might initially cause effects of number attraction that confound interference effects from NP2. When readers interpret the complex noun phrase (*apprentice of the carpenters*) as the subject of the singular verb (*was*), there might be an attraction effect from *carpenters* masking a potential number interference effect from NP2.

A second explanation for the absence of attraction comes from production research. The prepositional phrase with the attracting noun phrases was embedded in a relative clause preceding the main verb *was*. Thus, the noun phrases (*assistant* and *politician*) were syntactically separated from the verb phrase (*was*). Production studies like Bock and Cutting (1992) have shown that a local number attractor that is embedded in a relative clause can cause a number attraction effect at the following verb. However, the likelihood of such errors is significantly smaller when the number attractor is embedded in a relative clause (*The editor who rejected the* <u>*books*</u> (Bock & Cutting, 1992, p. 106)) and therefore syntactically further separated from the verb than when the attractor is part of a prepositional phrase (*The editor of the history* <u>*books*</u> (Bock & Cutting, 1992, p. 106)). Franck et al. (2002, 2006) argued that a noun that c-commands a verb (The prepositional phrase, like *the assistant of the politician* did not c-command the verb *was* in the materials of Experiment 3) and is therefore in a hierarchical relation with the verb is more likely to cause an attraction error at the verb than a noun that is not in a hierarchical relation with the verb. These principles may also apply to comprehension processes: a number attractor that is more syntactically separated from the verb may be less likely to affect the comprehension of the verb than a number attractor that c-commands the verb.

Finally, a third explanation of why there was no sign of an attraction effect in Experiment 3 is that there was a strong number interference effect from the third noun phrase in this experiment. This was observed in several early measures like first fixation duration and first pass time. Since the observed number interference effect was quite strong in Experiment 3, it might have overridden any small effects of number attraction.

The clear interference effects in Experiment 3 contrast with the findings in Experiments 1 and 2. Experiment 3 showed a number interference effect caused by the local noun phrase. While Experiment 1 showed no effects of number interference, the number interference effect in Experiment 2 was weak and occurred later than the relative clause effect. The absence of an interference effect in Experiments 1 and 2 might be due to the high activation of the subject of the relative clauses: a sentence subject, when followed by a single relative clause, might still be activated at the main verb and may be easily retrieved from memory. The interfering relative clause might not have caused enough information decay for an interference effect. The intervening region in Experiment 3 contained a subject-relative clause with two noun phrases connected by a preposition (this noun phrase served as the object of the relative clause). This prepositional phrase contained a noun phrase that increased the distance between subject and verb. Thus, the subject *chauffeur* in (3) had more time to decay in Experiment 3 than in Experiment 1 and 2. As a result, the reading times in Experiment 3 showed an effect of number interference in the early measures (first fixation duration, first-pass time).

However, the materials in Experiment 3 contained a potential confound. A number of the embedded verbs (e.g. *advised*) used in Experiment 3 were structurally ambiguous, e.g. with *advised* the following noun phrase could also be interpreted as the subject of a reduced relative clause (predicted sentence structure: *The janitor who advised (that) the apprentice of the carpenter was at the station's taxi rank (left).*). Thus, *was at* may be integrated with the noun phrase (*the apprentice of the carpenter*) instead of with the sentence subject *janitor*. This interpretation will only be ruled out at the end of the sentence when there is no verb to integrate the subject *janitor* with. This structural ambiguity of the embedded verb might have caused a reanalysis effect which might have masked other effects like number attraction. Therefore, Experiment 4 was conducted to rule out this explanation.

The materials used in Experiment 4 were similar to those of Experiment 3. In order to avoid the potential confound of structurally ambiguous verbs, the first verb was followed by a prepositional phrase (*argued with the customer of the directors*) rather than a noun phrase. All the other predictions about attraction and number interference effects are equivalent to the predictions made for Experiment 3.

4 (a) **plural second / local plural**
The secretary | who argued with | the customers of the directors | was on | the train | to the meeting.

(b) **plural second / local singular**

The secretary | who argued with | the customers of the director | was on | the train | to the meeting.

(c) **singular second / local plural**
The secretary | who argued with | the customer of the directors | was on | the train | to the meeting.

(d) **singular second / local singular**
The secretary | who argued with | the customer of the director | was on | the train | to the meeting.

Analysis of the reading times of Experiment 4 showed an effect of the number of the local noun phrase (*director(s)*) preceding the verb. There were longer first fixation durations at the spillover region (*the train*) when the local noun phrase was singular (*director*) than when the local noun phrase was plural (*directors*), which is an interference effect. These findings are in agreement with the findings of Experiment 3, which also showed longer first fixation durations when the local noun phrase was singular than when it was plural. This difference was reported for the critical region in Experiment 3 and not the spillover region unlike in Experiment 4. In addition to the effect of the number of the local noun phrase in the early first fixation duration measure, the analysis of the reading time measures showed a number effect of the second noun phrase in later measures: total reading times were longer when the second noun phrase was singular (*customer*) than when it was plural (*customers*) at the spillover region, which is in agreement with interference.

Experiment 4 supported the findings of the number interference effect reported in Experiment 3: there were longer reading times when the local noun phrase (*directors*) was plural than when it was singular. Like in Experiment 3, this effect was observed in first fixation duration, which is a measure of early processes. However, while this effect was observed at the critical verb region (*was at*) in Experiment 3, in Experiment 4 it was at the spillover region directly following the verb (*the train*). This difference might be a consequence of the changed verb phrases in Experiment 4 (Experiment 4 used verbs such as *who argued with* that were followed by a noun phrase that contained a prepositional phrase, whereas the verbs used in Experiment 4 were not followed by a preposition (like *greeted*), but these verbs could be followed by a noun phrase or a reduced complement clause.) Experiment 3 had structurally ambiguous, but shorter verb phrases *who greeted*). The interfering nouns in Experiment 3 (*customer* and *director*) where more integrated with the verb as a direct object than as a prepositional phrase (*with the customer of the director*) in Experiment 4. The closer integration of the direct object with the verb might explain why number interference was observed at the critical region *was at* in Experiment 3. As verb and object are already integrated with each other, the syntactic integration of verb and object is easier and faster than a verb with a prepositional phrase. Thus, since the integration of the prepositional phrase took longer, the number interference effect was observed later at the spillover region *the train* in Experiment 4.

There was also a number interference effect from the second noun phrase in Experiment 4. There were longer reading times when the second noun phrase was singular than when it was plural in total reading times. A number effect from the second noun phrase was not observed in Experiment 3. It was argued that the absence of a number interference effect from the second noun phrase in Experiment 3 was due to information decay: the memory trace of the second noun phrase may have decayed when readers processes NP3. There was a number interference effect of the second noun phrase (*customer(s)*) in Experiment 4, this suggests that the second noun phrase had not decayed much in Experiment 4. This might be a consequence of the change in the materials. The materials in Experiment 3 used verbs which could be followed either by a direct object or a reduced complement clause and therefore added a potential confound. The complex noun phrase could have been interpreted as the subject of the following singular verb resulting in an attraction effect that masks number interference from NP2 in Experiment 3. By using verb phrases that were followed by a prepositional phrase, this ambiguity was avoided in Experiment 4 and readers could not interpret the complex noun phrase as the subject of the verb. Thus, in Experiment 4 number interference from NP2 was not masked by number attraction from the complex noun phrase in subject position.

Interestingly, the number interference effect of the local noun was observed in both Experiments 3 (*politician(s)*) and 4 (*director(s)*) in the early measures. These effects were not observed in the later measure total reading time in Experiment 3 and 4. The finding that the number interference effect occurs in early measures, but not in the late measure suggests that number interference occurs instantaneously, but is short-lived. In Experiment 4, there was a number interference effect from NP2 (*customer*), which was more distant from the main verb *was on*, in the later total reading times. It was assumed that this effect didn't occur in Experiment 3 because of potential number attraction effects (from the complex noun phrase) masking the interference of NP2. The confound of Experiment 3 was avoided in Experiment 4 by replacing structurally ambiguous verbs like *welcomed* with verbs that were followed by a preposition like *argued with*. Without the confound of Experiment 3, there was an interference effect from NP2, however unlike number interference from the local noun phrase, this effect was only observed in the later reading time measure total reading time. This suggested that the number congruency of NP2 occurs due to interference during later checking procedures rather than early agreement processes.

There was no effect of number attraction in the reading time measures of Experiment 4. It was hypothesised that the absence of the NP2 effect in Experiment 3 might be indirect indication of number attraction due to the complex noun phrase erroneously being interpreted as the subject of the singular verb. This number attraction effect in Experiment 3 might have masked potential number interference from NP2. There was no effect of number attraction when this confound was avoided in Experiment 4, there was a number interference effect from NP2 in Experiment 4. Thus, the absence of a number attraction effect in Experiments 3 and 4 may be explained by the syntactic separation between the number attractor and the following verb (attractor embedded in relative clause).

Overall, Experiments 3 and 4 both found an effect of number interference of the local noun phrase. These effects occurred early in both experiments, but were not observed in later measures. This suggests that number interference occurs very early. However, while this effect occurred early it seems to be short-lived since there was no number interference effect of the local noun phrase in any of the later measures like total reading times. The number interference effect of the second noun phrase, on the other hand, occurred only in Experiment 4 and was observed in the later reading time measures. Thus, the number congruency of the second noun phrase caused interference during later checking processes. There was no effect of number attraction in either Experiments 3 and 4, which might be due to the sentence structure tested. Since the number attractor was deeply embedded, a local plural noun might not affect the reading times at the following singular verb.

The reading times of Experiments 1 to 4 seem to show different results about the occurrence of number interference in sentence processing. Experiment 2 showed weak number interference that occurred later than the relative clause effect. However, number interference was stronger in Experiments 3 and 4, and it occurred in early reading times measures. This suggests that number interference affects early agreement processes, though this effect doesn't occur in the later measures and therefore was argued to be short-lived.

There was a difference regarding when the number interference occurred between the first two experiments (Experiments 1 and 2) and the latter two experiments (Experiment 3 and 4). It was argued that the delay of the interference effect might be because the target subject has not decayed enough at the verb and therefore it only interfered during later wrap-up processes. The finding of an early number interference effect in Experiments 3 and 4 supports this hypothesis. There was more distance between the subject and its verb (subject-relative clause with embedded complex noun phrase) in Experiments 3 and 4 making retrieval of the subject more difficult since the subject had more time to decay. Given the theory described by Van Dyke and Lewis (2003); Lewis and Vasishth (2005), retrieval cue-overlap effects caused by different retrieval cues (e.g., animacy, number, syntactic cues) are expected to cause interference effects at the same time. Van Dyke and Lewis; Lewis and Vasishth do not qualitatively distinguish between cues that play a syntactic role, like case, which may cause interference earlier and cues describing semantic characteristics, like animacy, which may cause interference later. Interestingly, however, Van Dyke (2007) presented findings showing that interference due to syntactic cue-overlap occurred earlier than interference caused by the overlap of semantic cues. This discrepancy between the accounts described in Van Dyke and Lewis (2003) and the results of Van Dyke (2007) motivated Experiment 5. Experiments 3 and 4 found an early interference effect due to number congruency and Van Dyke (2007) found that interference due to syntactic cue-overlap occurred earlier than the interference effect caused by semantic cues, like animacy. Experiment 5 investigated the timing of the number congruency effect in comparison with interference caused by syntactic cue-overlap. If interference due to syntactic cue overlap occurs before interference due to other cues (as shown by Van Dyke (2007)), then it should also occur before the interference effect due to number congruency. Therefore, there should be an interference effect due to syntactic-cue overlap and (5c) and (5d) should have longer reading times than (5a) and (5b). There should also be a number interference effect, with longer reading times for the number congruent conditions (5b and 5d) than the number incongruent conditions (5a and 5c). The syntactic interference effect should occur earlier than the number congruency effect in Experiment 5.

5. (a) **low syn / nr incongruent**
   The presenter acknowledged that the photographer | who was chatting with the convincing journalists | has been | awarded | the prize.

   (b) **low syn / nr congruent**
   The presenter acknowledged that the photographer | who was chatting with the convincing journalist | has been | awarded | the prize.

   (c) **high syn / nr incongruent**
   The presenter acknowledged that the photographer | who professed that the journalists talked convincingly | has been | awarded | the prize.

(d) **high syn / nr congruent**
The presenter acknowledged that the photographer | who professed that the journalist talked convincingly | has been | awarded | the prize.

Experiment 5 showed a number interference effect from the local noun phrase (*journalist(s)*) in the early measures. In addition, there was also an interference effect due to the syntactic cue overlap in the later measures.

Similar to Experiments 3 and 4, the number interference effect in Experiment 5 was observed early in the first fixation duration measure and first-pass time. There was no effect of syntactic cue overlap in early first fixation duration and first-pass time measures. There was no effect of number interference in any of the later measures.

The findings of Experiment 5 together with the results of Experiment 3 and 4 suggest that number interference has a rapid effect on sentence processing. Number interference seems to affect early processes of agreement when a verb has to be attached to the previous structure and its number has to agree with the number of its subject. In addition, the findings of Experiment 5 suggest that these agreement processes between parts of the sentence occur before syntactic cues are used for hierarchical structure building.

The findings of Experiments 3, 4 and 5 also showed that while number interference occurs early, it is also short lived. There were no effects of number interference in any of the later measures in all three eye-tracking experiments. Thus, although number interference affects early agreement processes and thus is part of early structure building, it does not affect later processes of sentence wrap-up.

These findings seem to be inconsistent with the findings of Experiments 1 and 2, where number interference only occurred late, affecting final sentence wrap-up processes. However, this suggests that this delay of the number interference effect might be because the target subject did not decay enough and therefore could be easily retrieved from memory. The subject in Experiments 3, 4 and 5, on the other hand, had enough time to decay and thus, the number cue-overlap resulted in early interference effects.

One of the main questions that motivated Experiments 3 and 4 was whether number attraction could affect the comprehension of grammatical sentences. There was no indication that number attraction affected the comprehension of the sentences tested in Experiments 3 and 4. As mentioned earlier, this might be have been due to the syntactic embedding of the number attractor and therefore the number attractor and verb were syntactically highly separated.

Experiment 6 further investigated the question whether number attraction affects the comprehension of grammatical sentences. While number attraction might not affect early syntactic structure building processes, it might affect later reanalysis processes. Wagers et al. (2009) found number attraction effects for ungrammatical sentences. Thus, number attraction might be involved in later checking processes when readers try to resolve the ungrammaticality of the sentence. In order to test whether number attraction affects later processes of structural analysis, Experiment 6 contrasted sentences with (6a, 6b) or without an ambiguous region (6c, 6d). The ambiguous conditions (6a) and (6b) contained the verb *answered* which could either be used transitively (followed by a direct object *the cousin of the farmer*) or intransitively (not followed by an object).

In addition, in order to test whether number attraction can be caused by nouns that are not in a relative clause, the local attractor (*farmers*) preceded the verb *has to* in (6b) and (6d) and was not embedded in a relative clause. Thus, two effects are expected to occur at *has to*. First, there should be an effect of ambiguity: when readers originally interpret the noun phrase *the cousin of the farmer(s)* as the direct object of the first verb *answered*, *has to* cannot be integrated into this sentence structure. Therefore, integrating *has to* should initiate a reanalysis of the previous sentence structure in the ambiguous conditions (6a, 6b). Second, there should be a number attraction effect at *has to* in (6b, 6d). When the number information of the local noun (*farmer(s)*) affects agreement at the verb (*has*), a plural local noun (6b, 6d) should cause longer reading times at the singular verb than a singular local noun (6a, 6c). However, since number attraction might be part of later checking processes it is likely that attraction might affect processes of reanalysis: when readers encounter a structure that seems ungrammatical (which should occur in the ambiguous condition, when they try to integrate *has to*), they check the previously seen structure for an ambiguity in order to reanalyse the sentence. In case checking is affected by number attraction, reanalysis should be more difficult when the NP2 is plural.

6. (a) **ambiguous / singular NP2**
   After Virginia answered the cousin of the farmer | has to | think it | all over again.

   (b) **ambiguous / plural NP2**
   After Virginia answered the cousin of the farmers | has to | think it | all over again.

   (c) **unambiguous / singular NP2**
   After Virginia answered, the cousin of the farmer | has to | think it | all over again.

   (d) **unambiguous / plural NP2**
   After Virginia answered, the cousin of the farmers | has to | think it | all over again.

Similarity based interference makes a different prediction about the reading times at the verb (*has*) than number attraction. According to memory interference accounts, there should be longer reading times when the preceding noun phrase is singular (6a, 6c) than when it is plural (6b, 6d). The retrieval probe of the singular verb has more difficulty matching the retrieval cues with the target noun (*cousin*) when there is an similar singular noun than when there is a dissimilar plural noun in memory. However, the subject (*cousin*) and the verb (*has*) are only separated by one interfering noun phrase (*farmer*), therefore it might be that the subject is still active in memory and might be easily retrieved even though there is an interfering item. As a result there may be no number interference effects in Experiment 6.

Experiment 6 showed an interaction: regression-path times in the critical region (*has to*) were longer in the ambiguous conditions when the local noun phrase was plural in comparison to when the local noun phrase was singular.

In addition, the ambiguous conditions had longer reading times than the unambiguous conditions at several regions and measures.

The interaction showed evidence that number attraction can indeed affect comprehension processes in grammatical sentences. However, since the interaction showed that number attraction affected processes of reanalysis number attraction seems to be part of later checking processes that follow the processes of initial structure building.

10.2 What are the implications of the findings of the experiments?

10.2.1 Overview of the findings of the experiments

The findings of the experiments of this thesis show that there is number interference in sentence processing. Experiments 1 and 2 showed that number interference is weak, at the point of verb integration, when the distance between the subject and verb is relatively small, and therefore the activation of the subject is likely to be high. When the subject-verb distance is short, other temporarily stored items interfere only weakly with retrieval processes of the subject. Experiments 3, 4 and 5 showed that when the subject-verb distance was longer and the subject had enough time to decay the interference effect occurred early (in the early measures first fixation duration and first-pass time at the critical and at the spillover regions). However, this early effect was not long-lived since it was not observed in any of the later measures (regression-path time and total reading time). The observations of Experiment 5 showed that in comparison with syntactic interference effects, number interference occurred earlier than interference caused by syntactic cue overlap.

Number also plays an important role in agreement processes. However, the findings of experiments 1-5 did not show any effects of number attraction, but effects of number interference. The findings of Experiment 6, however, showed that number attraction affected reanalysis processes. Reanalysis difficulty reflects repair processes, when readers cannot grammatically integrate an incoming word into the already build sentence structure. In order to process the sentence, they have to reanalyse earlier parts of a sentence that contain a local ambiguity. Experiment 6 showed that number attraction affects repair processes like reanalysis.

10.2.2 What type of account is suggested?

Number is involved in both, retrieval and agreement processes. After revisiting the findings of the experiments of this thesis, the question remains: what are the underlying processes that, on the one hand, cause a number interference effect and, on the other hand, a number attraction effect? Both effects have been shown to affect comprehension in this thesis.

I suggest that both the number attraction and the number interference effect are effects of underlying agreement processes. Number interference occurs early and indicates a difficulty to identify and retrieve a target among similar items in memory. In contrast, the number attraction effect occurs late with other repair processes (like reanalysis) and is the result of retrieving the wrong noun phrase as the subject of the verb. When a verb needs to be integrated into a sentence structure, its number information is used to identify its subject. Retrieval cues of both the verb and the subject help with the rapid identification of the correct subject. This process is interfered with by temporarily stored items that are similar to the subject. As a result, the retrieval takes longer, but it is assumed that by the end the correct subject will be integrated with the verb. In Experiments 3, 4 and 5, this number interference effect occurred early (in first fixation duration and first-pass time), suggesting that at this stage readers consider both the correct subject and other noun phrases if the activation of the subject is low. According to the marking and morphing model by Eberhard et al. (2005), establishing the number agreement between a subject and its verb is part of early syntactic processing. Once the notional number of the subject is established, this will be transmitted to syntactic processes, which sets the number for agreeing elements binding the number information to structural positions in the sentence. Thus, number agreement processes are part of early structure building. Therefore, interfering with these agreement processes will result in number interference effects that can be observed early in sentence processing.

The number attraction effect, on the other hand, is not an early effect. Wagers et al. (2009) have shown number attraction effects for ungrammatical sentences and Experiment 6 has shown that number attraction affects reanalysis processes. When the disambiguating verb needs to be integrated (in Experiment 6), the reanalysis takes time and effort. The integration of the verb requires a reanalysis, which also includes the integration with the subject. The account proposed here claims that the agreement processes between verb and subject might be compromised by processes of repair (reanalysis in Experiment 6) resulting in the number attraction effect. Working at full capacity to resolve the structural ambiguity, the processor erroneously choses the local plural noun as the subject of the verb. Thus, the number attraction effect observed in Experiment 6 is actually a consequence of failed subject retrieval. While readers are busy to resolve the ambiguity, they might initially miss the number mismatch between the local noun and the verb. Only later will they detect the number mismatch between the verb and the noun (*farmers* and *has to*) and then search for the actual subject.

The point here is that number attraction effects in comprehension occur when readers try to resolve another problem within the sentence (either an ambiguity or they try to resolve an ungrammaticality). Number attraction is the result of wrong subject retrieval. Number interference, on the other hand, is a slow-down as a consequence of cue-overlap. There are too many items sharing the same number information, thus finding the correct target for retrieval is delayed. Thus both, the attraction effect and the number interference effect, are effects of retrieval interference. While attraction occurs due to the interference of another noun phrase and as a consequence the wrong subject is retrieved (repair processes like reanalysis or recovery from an ungrammaticality are affected), number interference effects arise due to the similarity between items that are potential targets for the retrieval: the retrieval of the correct target will be slowed down.

10.2.3 Predictions of the account and open questions

I suggested that the number attraction effect is a consequence of the retrieval of the incorrect subject during high processing load conditions. How could such a hypothesis be tested in another experiment? Consider the sample sentence from Experiment 6: *After Virginia answered the cousin of the farmer has to think it all over again.* If readers indeed interpreted the local noun (*farmer*) as the subject of the verb (*has*), this mistake might be detected in the condition where the local noun matches the number of the verb. Thus, the hypothesis of the wrong retrieval can actually be tested. An experiment might investigate the comprehension of the sentence using comprehension questions. If the local noun is erroneously interpreted as the subject (under high processing load) and this mistake will not be corrected (since there is no number mismatch), then readers should keep the interpretation that *farmer* is the subject of *has to*. Comprehension questions could directly probe for the subject of the verb *has*. A possible approach would be the following types of yes/no comprehension questions:

After Virginia answered the cousin of the farmer(s) has to think it all over again.

Yes question	**No question**
Did the cousin have to think it all over again?	Did the farmer(s) have to think it all over again?

According to the hypothesis proposed here, *farmer* should be a more likely subject than *farmers* because in the latter case, the interpretation has to be corrected during comprehension due to the number mismatch.

In order to explain the results from the experiments in this thesis, this model assumes that number interference effects occur early when the target subject had enough time to decay. However, interference does not result in clear effects when the subject didn't have enough time to decay. Experiment 2 found only a weak number interference effect since the subject-verb distance was small and therefore the subject activation is assumed to be high. Unlike the early strong number interference effects in Experiments 3-5, this weak effect was observed late at the sentence wrap-up region. Thus, it was argued that weak interference effects occur together with final wrap-up processes. However, Experiment 4 reported a weak interference effect from the NP2, which was also observed in a later measure (total reading times at the spillover region), but not at the final region of the sentence. Thus, the hypothesis that weak number interference effects occur together with final sentence wrap-up processes seems inconsistent with the findings of Experiment 4. What does that delay mean for the retrieval cue based parsing account? Van Dyke and Lewis (2003) claimed that the retrieval probe of the verb matches the different retrieval cues of the candidates simultaneously. Thus, the number interference effect, whether strong or weak, should occur at the same time as interference effects due to syntactic cue overlap. Given the predictions of the retrieval cue account, the findings suggest further research questions: Does the matching of the various retrieval cues of the retrieval probe with the candidates stored in memory really happen simultaneously and therefore in parallel? The findings in this thesis suggest that the cue overlap of different cues results in interference effects at different times. If retrieval cues are indeed used at different times during processing: What would be the time course of the different cues? The findings of Experiment 5 suggest that number cues are matched before syntactic cues for verb subcategorisation.

Besides number, verb subcategorisation and animacy information of the noun phrases, what are the other cues that can be matched against each other? Finally, is the weak interference effect that was found in Experiment 2 really because of the number cue-overlap?

11 Conclusion

Experiments 2, 3, 4 and 5 in this thesis showed that there is number interference in sentence processing. When the subject head had enough time to decay and there is a local (close distance to the verb) interfering noun phrase in memory, number interference occurs early and before structure building. Experiments 3, 4 and 5 showed that number interference was observed in the early measure first fixation duration and Experiment 5 showed that number interference occurs before structure building.

In Experiments 1 and 2 the subject head did not have enough time to decay and therefore the number interference effect was weak (occurred only in Experiment 2). When the head did not have enough time to decay number interference was weak and it occurred later than the relative clause effect as part of later checking processes. These findings are not in agreement with the account of Van Dyke and Lewis (2003) who predicted that the relative clause effect and the number interference effect should occur together at the point of verb integration. However, given the short distance between the subject and the verb, the subject noun might not have decayed and therefore could be retrieved from memory without problem. Thus, number interference occurred late as part of checking processes that occur during the processing of complex sentences like object relatives. Alternatively, the findings of Experiment 2 might also suggest that the difficulty associated with object relatives is not due to similarity based interference effects. Thus, the findings of Experiment 1 and 2 would be more in agreement with the accounts of locality and surprisal.

An interfering noun phrase that is more distant to the verb can also cause number interference, but this effect will occur later than the effect caused by an interfering noun that is closer to the verb. Experiment 4 showed that there is number interference from NP2 (*customer*) that is more distant to the verb than NP3 (*director*). This effect occurred in total reading times, while interference from NP3 was observed early in first fixation durations (in Experiments 3, 4 and 5). NP2 has more time to decay due to the long distance between NP2 and the verb in comparison to NP3, which has less time to decay because of the short distance to the verb. Because the information of NP2 is not as active as the information of NP3, the number interference effect of the NP2 does not occur early and seems to affect later checking processes.

The finding that activation plays a central role in the time-course of number interference effects in sentence processing is in agreement with the account of Lewis and Vasishth (2005) that described activation decay as an effect of distance in their similarity based interference model.

The effects of number attraction in comprehension are weak when the number attractor is embedded. Experiments 3 and 4 tested sentences when number attractors were embedded in a relative clause. Both experiments did not show any effects of number attraction. In addition, Experiment 5 also contained a relative clause with an embedded number attractor. There was no effect of number attraction at the following number inflected verb. These findings are in agreement with production research like Bock and Miller (1991) and Bock and Cutting (1992) that have shown that there are fewer attraction errors when the number attractor is embedded in a relative clause. Nicol et al. (1997), on the other hand, reported effects of number attraction from an embedded attractor in comprehension. The findings of Experiments 3,4 and 5 are inconsistent with Nicol et al. (1997).

However, Experiments 3 and 4 might have shown support for number attraction in an indirect way. One of the reasons that there was no number interference effect from the NP2 in Experiment 3 might have been due to a confound caused by some of the verbs used in the materials. In some of the sentences, readers could interpret the embedded NP2 as the subject of the main verb. In case readers initially interpreted condition (c) as *The fundraiser who welcomed that the helper of the sponsors was on the organising committee ....*, the plural NP3 before the singular verb could have induced a number attraction effect. This number attraction might have masked a number interference effect of the NP2 in some of the sentences of Experiment 3. When this confound was avoided in Experiment 4, there was a number interference effect from the NP2 observed in total reading times. Thus, in Experiments 3 and 4 no attraction effect may have occurred because the (opposite) interference effect was stronger.

The findings of Experiment 6 and Wagers et al. (2009) suggest that number attraction processes affect late checking and recovery procedures during sentence comprehension. Previous experiments investigating number attraction effects in comprehension showed unclear results. Pearlmutter et al. (1999) showed attraction effects, which might have been a spillover effect from plural noun phrases. Since plurals are longer (due to the plural marker *s*), they might take longer to read and these processes might have spilled over to the next word. In addition, Pearlmutter (2000) found attraction effects in comprehension from a singular number attractor. Interestingly, there was no attraction effect from a plural number attractor in Pearlmutter (2000). This finding is inconsistent with the production literature which reported stronger attraction effects from a plural number attractor than from a singular number attractor (Bock & Miller, 1991; Bock & Cutting, 1992; Franck et al., 2002; Solomon & Pearlmutter, 2004; Franck et al., 2006). Using offline measures Nicol et al. (1997) showed number attraction effects in comprehension. However, due to the offline task of the experiments in Nicol et al. (1997), it is unclear when these effects occurred during online processing.

Experiment 6 showed that number attraction made reanalysis processes more difficult: ambiguous sentences with a plural NP2 had longer regression path times than ambiguous sentences with a singular NP2. Reanalysis usually occurs when a new word cannot be integrated into the sentence structure built so far. Therefore, reanalysis is a recovery process when a word does not grammatically fit into a structure. This may be similar to recovery processes when readers encounter an ungrammatical sentence. Wagers et al. (2009) reported that number attraction affected the comprehension of ungrammatical sentences. Even though, the exact processes that are involved during the reading of ungrammatical sentences are unclear, when encountering an ungrammatical structure people search the structure for parsing mistakes (recovery process) similar to reanalysis. Thus, the findings of Experiment 6 and Wagers et al. (2009) suggest that attraction effects in comprehension might be involved during recovery processes when readers try to resolve ungrammatical sentence structures.

To summarise, the account proposed in this thesis claims that number interference and number attraction in comprehension are effects of subject retrieval processes. Number attraction in comprehension occurs because of the subject retrieval of the wrong noun during high processing load. Number interference, on the other hand, occurs due to the similarity between items that are subject candidates and thus delay subject retrieval. Number interference results in longer reading times and can be observed early during online sentence processing. Number attraction results in the retrieval of the wrong (local) subject. Realising this mistake, the correction results in longer regression-path times, when readers need to search for the right subject of the verb.

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A Appendix

A.1 Experiment 1: sentence stimuli

1. (a) The student that / the cleaner hates / slept at / the desk / for a while.
   The students that / the cleaners hate / slept at / the desk / for a while.

   (b) The student that / hates the cleaner / slept at / the desk / for a while.
   The students that / hate the cleaners / slept at / the desk / for a while.

   (c) The students that / the cleaner hates / slept at / the desk / for a while.
   The student that / the cleaners hate / slept at / the desk / for a while.

   (d) The students that / hate the cleaner / slept at / the desk / for a while.
   The student that / hates the cleaners / slept at / the desk / for a while.

2. (a) The guest that / the host meets / searched / for the house / for an hour.
   The guests that / the hosts meet / searched / for the house / for an hour.

   (b) The guest that / meets the host / searched / for the house / for an hour.
   The guests that / meet the hosts / searched / for the house / for an hour.

   (c) The guests that / the host meets / searched / for the house / for an hour.
   The guest that / the hosts meet / searched / for the house / for an hour.

   (d) The guests that / meet the host / searched / for the house / for an hour.
   The guest that / meets the hosts / searched / for the house / for an hour.

3. (a) The dwarf that / the gnome assaults / performed / for the king / in the castle.
   The dwarfs that / the gnomes assault / performed / for the king / in the castle.

   (b) The dwarf that / assaults the gnome / performed / for the king / in the castle.
   The dwarfs that / assault the gnomes / performed / for the king / in the castle.

   (c) The dwarfs that / the gnome assaults / performed / for the king / in the castle.
   The dwarf that / the gnomes assault / performed / for the king / in the castle.

(d) The dwarfs that / assault the gnome / performed / for the king / in the castle.
The dwarf that / assaults the gnomes / performed / for the king / in the castle.

4. (a) The director that / the philosopher ridicules / called for / a doctor / in a panic.
The directors that / the philosophers ridicule / called for / a doctor / in a panic.

(b) The director that / ridicules the philosopher / called for / a doctor / in a panic.
The directors that / ridicule the philosophers / called for / a doctor / in a panic.

(c) The directors that / the philosopher ridicules / called for / a doctor / in a panic.
The director that / the philosophers ridicule / called for / a doctor / in a panic.

(d) The directors that / ridicule the philosopher / called for / a doctor / in a panic.
The director that / ridicules the philosophers / called for / a doctor / in a panic.

5. (a) The clown that / the juggler photographs / decided / very quickly / what to film.
The clowns that / the jugglers photograph / decided / very quickly / what to film.

(b) The clown that / photographs the juggler / decided / very quickly / what to film.
The clowns that / photograph the jugglers / decided / very quickly / what to film.

(c) The clowns that / the juggler photographs / decided / very quickly / what to film.
The clown that / the jugglers photograph / decided / very quickly / what to film.

(d) The clowns that / photograph the juggler / decided / very quickly / what to film.
The clown that / photographs the jugglers / decided / very quickly / what to film.

6. (a) The guard that / the sheriff protects / lived in / New Mexico / for many years.
The guards that / the sheriffs protect / lived in / New Mexico / for many years.

(b) The guard that / protects the sheriff / lived in / New Mexico / for many years.
The guards that / protect the sheriffs / lived in / New Mexico / for many years.

(c) The guards that / the sheriff protects / lived in / New Mexico / for many years.
The guard that / the sheriffs protect / lived in / New Mexico / for many years.

(d) The guards that / protect the sheriff / lived in / New Mexico / for many years.
The guard that / protects the sheriffs / lived in / New Mexico / for many years.

7. (a) The trader that / the retailer injures / discussed / the proposal / in great detail.
The traders that / the retailers injure / discussed / the proposal / in great detail.

(b) The trader that / injures the retailer / discussed / the proposal / in great detail.
The traders that / injure the retailers / discussed / the proposal / in great detail.

(c) The traders that / the retailer injures / discussed / the proposal / in great detail.
The trader that / the retailers injure / discussed / the proposal / in great detail.

(d) The traders that / injure the retailer / discussed / the proposal / in great detail.
The trader that / injures the retailers / discussed / the proposal / in great detail.

8. (a) The academic that / the idealist defends / spoiled / the surprise / to many people.
The academics that / the idealists defend / spoiled / the surprise / to many people.

(b) The academic that / defends the idealist / spoiled / the surprise / to many people.
The academics that / defend the idealists / spoiled / the surprise / to many people.

(c) The academics that / the idealist defends / spoiled / the surprise / to many people.
The academic that / the idealists defend / spoiled / the surprise / to many people.

(d) The academics that / defend the idealist / spoiled / the surprise / to many people.
The academic that / defends the idealists / spoiled / the surprise / to many people.

9. (a) The graduate that / the expert greets / instructed / the English class / about grammar.
The graduates that / the experts greet / instructed / the English class / about grammar.

(b) The graduate that / greets the expert / instructed / the English class / about grammar.
The graduates that / greet the experts / instructed / the English class / about grammar.

(c) The graduates that / the expert greets / instructed / the English class / about grammar.
The graduate that / the experts greet / instructed / the English class / about grammar.

(d) The graduates that / greet the expert / instructed / the English class / about grammar.
The graduate that / greets the experts / instructed / the English class / about grammar.

10. (a) The villain that / the prisoner deceives / gave way / to despair / almost immediately.
The villains that / the prisoners deceive / gave way / to despair / almost immediately.

(b) The villain that / deceives the prisoner / gave way / to despair / almost immediately.
The villains that / deceive the prisoners / gave way / to despair / almost immediately.

(c) The villains that / the prisoner deceives / gave way / to despair / almost immediately.
The villain that / the prisoners deceive / gave way / to despair / almost immediately.

(d) The villains that / deceive the prisoner / gave way / to despair / almost immediately.
The villain that / deceives the prisoners / gave way / to despair / almost immediately.

11. (a) The producer that / the actor invites / insulted / the secretary / with the remark.
The producers that / the actors invite / insulted / the secretary / with the remark.

(b) The producer that / invites the actor / insulted / the secretary / with the remark.
The producers that / invite the actors / insulted / the secretary / with the remark.

(c) The producers that / the actor invites / insulted / the secretary / with the remark.
The producer that / the actors invite / insulted / the secretary / with the remark.

(d) The producers that / invite the actor / insulted / the secretary / with the remark.
The producer that / invites the actors / insulted / the secretary / with the remark.

12. (a) The wizard that / the ghost pursues / visited / the town / a few times.
The wizards that / the ghosts pursue / visited / the town / a few times.

(b) The wizard that / pursues the ghost / visited / the town / a few times.
The wizards that / pursue the ghosts / visited / the town / a few times.

(c) The wizards that / the ghost pursues / visited / the town / a few times.
The wizard that / the ghosts pursue / visited / the town / a few times.

(d) The wizards that / pursue the ghost / visited / the town / a few times.
The wizard that / pursues the ghosts / visited / the town / a few times.

13. (a) The banker that / the accountant helps / counted / the money / several times.
The bankers that / the accountants help / counted / the money / several times.

(b) The banker that / helps the accountant / counted / the money / several times.
The bankers that / help the accountants / counted / the money / several times.

(c) The bankers that / the accountant helps / counted / the money / several times.
The banker that / the accountants help / counted / the money / several times.

(d) The bankers that / help the accountant / counted / the money / several times.
The banker that / helps the accountants / counted / the money / several times.

14. (a) The guitarist that / the pianist frightens / seemed to / be hungry / and very tired.
The guitarists that / the pianists frighten / seemed to / be hungry / and very tired.

(b) The guitarist that / frightens the pianist / seemed to / be hungry / and very tired.
The guitarists that / frighten the pianists / seemed to / be hungry / and very tired.

(c) The guitarists that / the pianist frightens / seemed to / be hungry / and very tired.
The guitarist that / the pianists frighten / seemed to / be hungry / and very tired.

(d) The guitarists that / frighten the pianist / seemed to / be hungry / and very tired.
The guitarist that / frightens the pianists / seemed to / be hungry / and very tired.

15. (a) The peasant that / the shepherd wakes / hoped for / a solution / to the problem.
The peasants that / the shepherds wake / hoped for / a solution / to the problem.

(b) The peasant that / wakes the shepherd / hoped for / a solution / to the problem.
The peasants that / wake the shepherds / hoped for / a solution / to the problem.

(c) The peasants that / the shepherd wakes / hoped for / a solution / to the problem.
The peasant that / the shepherds wake / hoped for / a solution / to the problem.

(d) The peasants that / wake the shepherd / hoped for / a solution / to the problem.
The peasant that / wakes the shepherds / hoped for / a solution / to the problem.

16. (a) The governor that / the senator provokes / voted against / the proposal / last week.
The governors that / the senators provoke / voted against / the proposal / last week.

(b) The governor that / provokes the senator / voted against / the proposal / last week.
The governors that / provoke the senators / voted against / the proposal / last week.

(c) The governors that / the senator provokes / voted against / the proposal / last week.
The governor that / the senators provoke / voted against / the proposal / last week.

(d) The governors that / provoke the senator / voted against / the proposal / last week.
The governor that / provokes the senators / voted against / the proposal / last week.

17. (a) The architect that / the builder blames / drove to / the airport / in a limousine.
The architects that / the builders blame / drove to / the airport / in a limousine.

(b) The architect that / blames the builder / drove to / the airport / in a limousine.
The architects that / blame the builders / drove to / the airport / in a limousine.

(c) The architects that / the builder blames / drove to / the airport / in a limousine.
The architect that / the builders blame / drove to / the airport / in a limousine.

(d) The architects that / blame the builder / drove to / the airport / in a limousine.
The architect that / blames the builders / drove to / the airport / in a limousine.

18. (a) The waiter that / the barmaid surprises / spoke to / the neighbour / two days ago.
The waiters that / the barmaids surprise / spoke to / the neighbour / two days ago.

(b) The waiter that / surprises the barmaid / spoke to / the neighbour / two days ago.
The waiters that / surprise the barmaids / spoke to / the neighbour / two days ago.

(c) The waiters that / the barmaid surprises / spoke to / the neighbour / two days ago.
The waiter that / the barmaids surprise / spoke to / the neighbour / two days ago.

(d) The waiters that / surprise the barmaid / spoke to / the neighbour / two days ago.
The waiter that / surprises the barmaids / spoke to / the neighbour / two days ago.

19. (a) The plumber that / the electrician hires / worked on / the project / during the summer.
The plumbers that / the electricians hire / worked on / the project / during the summer.

(b) The plumber that / hires the electrician / worked on / the project / during the summer.
The plumbers that / hire the electricians / worked on / the project / during the summer.

(c) The plumbers that / the electrician hires / worked on / the project / during the summer.
The plumber that / the electricians hire / worked on / the project / during the summer.

(d) The plumbers that / hire the electrician / worked on / the project / during the summer.
The plumber that / hires the electricians / worked on / the project / during the summer.

20. (a) The poet that / the painter despises / cared for / the family / from Ethiopia.
The poets that / the painters despise / cared for / the family / from Ethiopia.

(b) The poet that / despises the painter / cared for / the family / from Ethiopia.
The poets that / despise the painters / cared for / the family / from Ethiopia.

(c) The poets that / the painter despises / cared for / the family / from Ethiopia.
The poet that / the painters despise / cared for / the family / from Ethiopia.

(d) The poets that / despise the painter / cared for / the family / from Ethiopia.
The poet that / despises the painters / cared for / the family / from Ethiopia.

21. (a) The violinist that / the composer offends / watched / the show / on the Internet.
The violinists that / the composers offend / watched / the show / on the Internet.

(b) The violinist that / offends the composer / watched / the show / on the Internet.
The violinists that / offend the composers / watched / the show / on the Internet.

(c) The violinists that / the composer offends / watched / the show / on the Internet.
The violinist that / the composers offend / watched / the show / on the Internet.

(d) The violinists that / offend the composer / watched / the show / on the Internet.
The violinist that / offends the composers / watched / the show / on the Internet.

22. (a) The lawyer that / the defendant irritates / remembered / the case / from the story.
The lawyers that / the defendants irritate / remembered / the case / from the story.

(b) The lawyer that / irritates the defendant / remembered / the case / from the story.
The lawyers that / irritate the defendants / remembered / the case / from the story.

(c) The lawyers that / the defendant irritates / remembered / the case / from the story.
The lawyer that / the defendants irritate / remembered / the case / from the story.

(d) The lawyers that / irritate the defendant / remembered / the case / from the story.
The lawyer that / irritates the defendants / remembered / the case / from the story.

23. (a) The detective that / the reporter criticizes / returned / immediately / from the trip.
The detectives that / the reporters criticize / returned / immediately / from the trip.

(b) The detective that / criticizes the reporter / returned / immediately / from the trip.
The detectives that / criticize the reporters / returned / immediately / from the trip.

(c) The detectives that / the reporter criticizes / returned / immediately / from the trip.
The detective that / the reporters criticize / returned / immediately / from the trip.

(d) The detectives that / criticize the reporter / returned / immediately / from the trip.
The detective that / criticizes the reporters / returned / immediately / from the trip.

24. (a) The author that / the general troubles / answered / all questions / from the judge.
The authors that / the generals trouble / answered / all questions / from the judge.

(b) The author that / troubles the general / answered / all questions / from the judge.
The authors that / trouble the generals / answered / all questions / from the judge.

(c) The authors that / the general troubles / answered / all questions / from the judge.
The author that / the generals trouble / answered / all questions / from the judge.

(d) The authors that / trouble the general / answered / all questions / from the judge.
The author that / troubles the generals / answered / all questions / from the judge.

25. (a) The actor that / the comedian interrupts / played a / difficult scene / on the stage.
The actors that / the comedians interrupt / played a / difficult scene / on the stage.

(b) The actor that / interrupts the comedian / played a / difficult scene / on the stage.
The actors that / interrupt the comedians / played a / difficult scene / on the stage.

(c) The actors that / the comedian interrupts / played a / difficult scene / on the stage.
The actor that / the comedians interrupt / played a / difficult scene / on the stage.

(d) The actors that / interrupt the comedian / played a / difficult scene / on the stage.
The actor that / interrupts the comedians / played a / difficult scene / on the stage.

26. (a) The judge that / the professor impresses / appeared / very stressed / about the situation.
The judges that / the professors impress / appeared / very stressed / about the situation.

(b) The judge that / impresses the professor / appeared / very stressed / about the situation.
The judges that / impress the professors / appeared / very stressed / about the situation.

(c) The judges that / the professor impresses / appeared / very stressed / about the situation.
The judge that / the professors impress / appeared / very stressed / about the situation.

(d) The judges that / impress the professor / appeared / very stressed / about the situation.
The judge that / impresses the professors / appeared / very stressed / about the situation.

27. (a) The nurse that / the paramedic supports / ate a nice / lunch after / the movie.
The nurses that / the paramedics support / ate a nice / lunch after / the movie.

(b) The nurse that / supports the paramedic / ate a nice / lunch after / the movie.
The nurses that / support the paramedics / ate a nice / lunch after / the movie.

(c) The nurses that / the paramedic supports / ate a nice / lunch after / the movie.
The nurse that / the paramedics support / ate a nice / lunch after / the movie.

(d) The nurses that / support the paramedic / ate a nice / lunch after / the movie.
The nurse that / supports the paramedics / ate a nice / lunch after / the movie.

28. (a) The engineer that / the mechanic dislikes / complained / about work / in a loud voice.
The engineers that / the mechanics dislike / complained / about work / in a loud voice.

(b) The engineer that / dislikes the mechanic / complained / about work / in a loud voice.
The engineers that / dislike the mechanics / complained / about work / in a loud voice.

(c) The engineers that / the mechanic dislikes / complained / about work / in a loud voice.
The engineer that / the mechanics dislike / complained / about work / in a loud voice.

(d) The engineers that / dislike the mechanic / complained / about work / in a loud voice.
The engineer that / dislikes the mechanics / complained / about work / in a loud voice.

29. (a) The warrior that / the knight attacks / looked very / scary with / the weapon.
The warriors that / the knights attack / looked very / scary with / the weapon.

(b) The warrior that / attacks the knight / looked very / scary with / the weapon.
The warriors that / attack the knights / looked very / scary with / the weapon.

(c) The warriors that / the knight attacks / looked very / scary with / the weapon.
The warrior that / the knights attack / looked very / scary with / the weapon.

(d) The warriors that / attack the knightÊ/ looked very / scary with / the weapon.
The warrior that / attacks the knights / looked very / scary with / the weapon.

30. (a) The local that / the tourist amuses / disappeared / in the dark / and sang a tune.
The locals that / the tourists amuse / disappeared / in the dark / and sang a tune.

(b) The local that / amuses the tourist / disappearedÊ/ in the dark / and sang a tune.
The locals that / amuse the tourists / disappeared / in the dark / and sang a tune.

(c) The locals that / the tourist amuses / disappeared / in the dark / and sang a tune.
The local that / the tourists amuse / disappeared / in the dark / and sang a tune.

(d) The locals that / amuse the tourist / disappeared / in the dark / and sang a tune.
The local that / amuses the tourists / disappeared / in the dark / and sang a tune.

31. (a) The singer that / the dancer pleases / misunderstood / the question / about the dance.
The singers that / the dancers please / misunderstood / the question / about the dance.

(b) The singer that / pleases the dancer / misunderstood / the question / about the dance.
The singers that / please the dancers / misunderstood / the question / about the dance.

(c) The singers that / the dancer pleases / misunderstood / the question / about the dance.
The singer that / the dancers please / misunderstood / the question / about the dance.

(d) The singers that / please the dancer / misunderstood / the question / about the dance.
The singer that / pleases the dancers / misunderstood / the question / about the dance.

32. (a) The scientist that / the inventor entertains / delivered / the products / according to plan.
The scientists that / the inventors entertain / delivered / the products / according to plan.

(b) The scientist that / entertains the inventor / delivered / the products / according to plan.
The scientists that / entertain the inventors / delivered / the products / according to plan.

(c) The scientists that / the inventor entertains / delivered / the products / according to plan.
The scientist that / the inventors entertain / delivered / the products / according to plan.

(d) The scientists that / entertain the inventor / delivered / the products / according to plan.
The scientist that / entertains the inventors / delivered / the products / according to plan.

A.2 Experiment 2: sentence stimuli

1. (a) The student that / the cleaner hates / slept at / the desk.
   The students that / the cleaners hate / slept at / the desk.

   (b) The student that / hates the cleaner / slept at / the desk.
   The students that / hate the cleaners / slept at / the desk.

   (c) The students that / the cleaner hates / slept at / the desk.
   The student that / the cleaners hate / slept at / the desk.

   (d) The students that / hate the cleaner / slept at / the desk.
   The student that / hates the cleaners / slept at / the desk.

2. (a) The guest that / the host meets / searched / for the house.
   The guests that / the hosts meet / searched / for the house.

   (b) The guest that / meets the host / searched / for the house.
   The guests that / meet the hosts / searched / for the house.

   (c) The guests that / the host meets / searched / for the house.
   The guest that / the hosts meet / searched / for the house.

   (d) The guests that / meet the host / searched / for the house.
   The guest that / meets the hosts / searched / for the house.

3. (a) The dwarf that / the gnome assaults / performed / for the king.
The dwarfs that / the gnomes assault / performed / for the king.

(b) The dwarf that / assaults the gnome / performed / for the king.
The dwarfs that / assault the gnomes / performed / for the king.

(c) The dwarfs that / the gnome assaults / performed / for the king.
The dwarf that / the gnomes assault / performed / for the king.

(d) The dwarfs that / assault the gnome / performed / for the king.
The dwarf that / assaults the gnomes / performed / for the king.

4. (a) The director that / the philosopher ridicules / called / for a doctor.
The directors that / the philosophers ridicule / called / for a doctor.

(b) The director that / ridicules the philosopher / called / for a doctor.
The directors that / ridicule the philosophers / called / for a doctor.

(c) The directors that / the philosopher ridicules / called / for a doctor.
The director that / the philosophers ridicule / called / for a doctor.

(d) The directors that / ridicule the philosopher / called / for a doctor.
The director that / ridicules the philosophers / called / for a doctor.

5. (a) The clown that / the juggler photographs / decided / very quickly.
The clowns that / the jugglers photograph / decided / very quickly.

(b) The clown that / photographs the juggler / decided / very quickly.
The clowns that / photograph the jugglers / decided / very quickly.

(c) The clowns that / the juggler photographs / decided / very quickly.
The clown that / the jugglers photograph / decided / very quickly.

(d) The clowns that / photograph the juggler / decided / very quickly.
The clown that / photographs the jugglers / decided / very quickly.

6. (a) The guard that / the sheriff holds / lived in / New Mexico.
The guards that / the sheriffs hold / lived in / New Mexico.

(b) The guard that / holds the sheriff / lived in / New Mexico.
The guards that / hold the sheriffs / lived in / New Mexico.

(c) The guards that / the sheriff holds / lived in / New Mexico.
The guard that / the sheriffs hold / lived in / New Mexico.

(d) The guards that / hold the sheriff / lived in / New Mexico.
The guard that / holds the sheriffs / lived in / New Mexico.

7. (a) The trader that / the retailer injures / discussed / the proposal.
The traders that / the retailers injure / discussed / the proposal.

(b) The trader that / injures the retailer / discussed / the proposal.
The traders that / injure the retailers / discussed / the proposal.

(c) The traders that / the retailer injures / discussed / the proposal.
The trader that / the retailers injure / discussed / the proposal.

(d) The traders that / injure the retailer / discussed / the proposal.
The trader that / injures the retailers / discussed / the proposal.

8. (a) The academic that / the idealist defends / spoiled / the surprise.
The academics that / the idealists defend / spoiled / the surprise.

(b) The academic that / defends the idealist / spoiled / the surprise.
The academics that / defend the idealists / spoiled / the surprise.

(c) The academics that / the idealist defends / spoiled / the surprise.
The academic that / the idealists defend / spoiled / the surprise.

(d) The academics that / defend the idealist / spoiled / the surprise.
The academic that / defends the idealists / spoiled / the surprise.

9. (a) The graduate that / the expert greets / instructed / the English class.
The graduates that / the experts greet / instructed / the English class.

(b) The graduate that / greets the expert / instructed / the English class.
The graduates that / greet the experts / instructed / the English class.

(c) The graduates that / the expert greets / instructed / the English class.
The graduate that / the experts greet / instructed / the English class.

(d) The graduates that / greet the expert / instructed / the English class.
The graduate that / greets the experts / instructed / the English class.

10. (a) The villain that / the prisoner deceives / gave way / to despair.
The villains that / the prisoners deceive / gave way / to despair.

(b) The villain that / deceives the prisoner / gave way / to despair.
The villains that / deceive the prisoners / gave way / to despair.

(c) The villains that / the prisoner deceives / gave way / to despair.
The villain that / the prisoners deceive / gave way / to despair.

(d) The villains that / deceive the prisoner / gave way / to despair.
The villain that / deceives the prisoners / gave way / to despair.

11. (a) The producer that / the actor invites / insulted / the secretary.
The producers that / the actors invite / insulted / the secretary.

(b) The producer that / invites the actor / insulted / the secretary.
The producers that / invite the actors / insulted / the secretary.

(c) The producers that / the actor invites / insulted / the secretary.
The producer that / the actors invite / insulted / the secretary.

(d) The producers that / invite the actor / insulted / the secretary.
The producer that / invites the actors / insulted / the secretary.

12. (a) The wizard that / the ghost pursues / visited / the town.
The wizards that / the ghosts pursue / visited / the town.

(b) The wizard that / pursues the ghost / visited / the town.
The wizards that / pursue the ghosts / visited / the town.

(c) The wizards that / the ghost pursues / visited / the town.
The wizard that / the ghosts pursue / visited / the town.

(d) The wizards that / pursue the ghost / visited / the town.
The wizard that / pursues the ghosts / visited / the town.

13. (a) The banker that / the accountant helps / counted / the money.
The bankers that / the accountants help / counted / the money.

(b) The banker that / helps the accountant / counted / the money.
The bankers that / help the accountants / counted / the money.

(c) The bankers that / the accountant helps / counted / the money.
The banker that / the accountants help / counted / the money.

(d) The bankers that / help the accountant / counted / the money.
The banker that / helps the accountants / counted / the money.

14. (a) The guitarist that / the pianist frightens / seemed / to be very hungry.
The guitarists that / the pianists frighten / seemed / to be very hungry.

(b) The guitarist that / frightens the pianist / seemed / to be very hungry.
The guitarists that / frighten the pianists / seemed / to be very hungry.

(c) The guitarists that / the pianist frightens / seemed / to be very hungry.
The guitarist that / the pianists frighten / seemed / to be very hungry.

(d) The guitarists that / frighten the pianist / seemed / to be very hungry.
The guitarist that / frightens the pianists / seemed / to be very hungry.

15. (a) The peasant that / the shepherd wakes / hoped for / a solution.
The peasants that / the shepherds wake / hoped for / a solution.

(b) The peasant that / wakes the shepherd / hoped for / a solution.
The peasants that / wake the shepherds / hoped for / a solution.

(c) The peasants that / the shepherd wakes / hoped for / a solution.
The peasant that / the shepherds wake / hoped for / a solution.

(d) The peasants that / wake the shepherd / hoped for / a solution.
The peasant that / wakes the shepherds / hoped for / a solution.

16. (a) The governor that / the senator provokes / voted against / the proposal.
The governors that / the senators provoke / voted against / the proposal.

(b) The governor that / provokes the senator / voted against / the proposal.
The governors that / provoke the senators / voted against / the proposal.

(c) The governors that / the senator provokes / voted against / the proposal.
The governor that / the senators provoke / voted against / the proposal.

(d) The governors that / provoke the senator / voted against / the proposal.
The governor that / provokes the senators / voted against / the proposal.

17. (a) The architect that / the builder blames / drove to / the airport.
The architects that / the builders blame / drove to / the airport.

(b) The architect that / blames the builder / drove to / the airport.
The architects that / blame the builders / drove to / the airport.

(c) The architects that / the builder blames / drove to / the airport.
The architect that / the builders blame / drove to / the airport.

(d) The architects that / blame the builder / drove to / the airport.
The architect that / blames the builders / drove to / the airport.

18. (a) The waiter that / the barmaid surprises / spoke to / the neighbour.
The waiters that / the barmaids surprise / spoke to / the neighbour.

(b) The waiter that / surprises the barmaid / spoke to / the neighbour.
The waiters that / surprise the barmaids / spoke to / the neighbour.

(c) The waiters that / the barmaid surprises / spoke to / the neighbour.
The waiter that / the barmaids surprise / spoke to / the neighbour.

(d) The waiters that / surprise the barmaid / spoke to / the neighbour.
The waiter that / surprises the barmaids / spoke to / the neighbour.

19. (a) The plumber that / the electrician hires / worked on / the project.
The plumbers that / the electricians hire / worked on / the project.

(b) The plumber that / hires the electrician / worked on / the project.
The plumbers that / hire the electricians / worked on / the project.

(c) The plumbers that / the electrician hires / worked on / the project.
The plumber that / the electricians hire / worked on / the project.

(d) The plumbers that / hire the electrician / worked on / the project.
The plumber that / hires the electricians / worked on / the project.

20. (a) The poet that / the painter despises / cared for / the family.
The poets that / the painters despise / cared for / the family.

(b) The poet that / despises the painter / cared for / the family.
The poets that / despise the painters / cared for / the family.

(c) The poets that / the painter despises / cared for / the family.
The poet that / the painters despise / cared for / the family.

(d) The poets that / despise the painter / cared for / the family.
The poet that / despises the painters / cared for / the family.

21. (a) The violinist that / the composer offends / watched / the show.
The violinists that / the composers offend / watched / the show.

(b) The violinist that / offends the composer / watched / the show.
The violinists that / offend the composers / watched / the show.

(c) The violinists that / the composer offends / watched / the show.
The violinist that / the composers offend / watched / the show.

(d) The violinists that / offend the composer / watched / the show.
The violinist that / offends the composers / watched / the show.

22. (a) The lawyer that / the defendant irritates / remembered / the case.
The lawyers that / the defendants irritate / remembered / the case.

(b) The lawyer that / irritates the defendant / remembered / the case.
The lawyers that / irritate the defendants / remembered / the case.

(c) The lawyers that / the defendant irritates / remembered / the case.
The lawyer that / the defendants irritate / remembered / the case.

(d) The lawyers that / irritate the defendant / remembered / the case.
The lawyer that / irritates the defendants / remembered / the case.

23. (a) The detective that / the reporter criticizes / returned / immediately.
The detectives that / the reporters criticize / returned / immediately.

(b) The detective that / criticizes the reporter / returned / immediately.
The detectives that / criticize the reporters / returned / immediately.

(c) The detectives that / the reporter criticizes / returned / immediately.
The detective that / the reporters criticize / returned / immediately.

(d) The detectives that / criticize the reporter / returned / immediately.
The detective that / criticizes the reporters / returned / immediately.

24. (a) The author that / the general troubles / answered / all questions.
The authors that / the generals trouble / answered / all questions.

(b) The author that / troubles the general / answered / all questions.
The authors that / trouble the generals / answered / all questions.

(c) The authors that / the general troubles / answered / all questions.
The author that / the generals trouble / answered / all questions.

(d) The authors that / trouble the general / answered / all questions.
The author that / troubles the generals / answered / all questions.

25. (a) The actor that / the comedian interrupts / played / a difficult scene.
The actors that / the comedians interrupt / played / a difficult scene.

(b) The actor that / interrupts the comedian / played / a difficult scene.
The actors that / interrupt the comedians / played / a difficult scene.

(c) The actors that / the comedian interrupts / played / a difficult scene.
The actor that / the comedians interrupt / played / a difficult scene.

(d) The actors that / interrupt the comedian / played / a difficult scene.
The actor that / interrupts the comedians / played / a difficult scene.

26. (a) The judge that / the professor impresses / appeared / very stressed.
The judges that / the professors impress / appeared / very stressed.

(b) The judge that / impresses the professor / appeared / very stressed.
The judges that / impress the professors / appeared / very stressed.

(c) The judges that / the professor impresses / appeared / very stressed.
The judge that / the professors impress / appeared / very stressed.

(d) The judges that / impress the professor / appeared / very stressed.
The judge that / impresses the professors / appeared / very stressed.

27. (a) The nurse that / the paramedic supports / ate a very / nice lunch.
The nurses that / the paramedics support / ate a very / nice lunch.

(b) The nurse that / supports the paramedic / ate a very / nice lunch.
The nurses that / support the paramedics / ate a very / nice lunch.

(c) The nurses that / the paramedic supports / ate a very / nice lunch.
The nurse that / the paramedics support / ate a very / nice lunch.

(d) The nurses that / support the paramedic / ate a very / nice lunch.
The nurse that / supports the paramedics / ate a very / nice lunch.

28. (a) The engineer that / the mechanic dislikes / complained / about work.
The engineers that / the mechanics dislike / complained / about work.

(b) The engineer that / dislikes the mechanic / complained / about work.
The engineers that / dislike the mechanics / complained / about work.

(c) The engineers that / the mechanic dislikes / complained / about work.
The engineer that / the mechanics dislike / complained / about work.

(d) The engineers that / dislike the mechanic / complained / about work.
The engineer that / dislikes the mechanics / complained / about work.

29. (a) The warrior that / the knight attacks / looked / very scary indeed.
The warriors that / the knights attack / looked / very scary indeed.

(b) The warrior that / attacks the knight / looked / very scary indeed.
The warriors that / attack the knights / looked / very scary indeed.

(c) The warriors that / the knight attacks / looked / very scary indeed.
The warrior that / the knights attack / looked / very scary indeed.

(d) The warriors that / attack the knight / looked / very scary indeed.
The warrior that / attacks the knights / looked / very scary indeed.

30. (a) The local that / the tourist amuses / disappeared / in the dark.
The locals that / the tourists amuse / disappeared / in the dark.

(b) The local that / amuses the tourist / disappeared / in the dark.
The locals that / amuse the tourists / disappeared / in the dark.

(c) The locals that / the tourist amuses / disappeared / in the dark.
The local that / the tourists amuse / disappeared / in the dark.

(d) The locals that / amuse the tourist / disappeared / in the dark.
The local that / amuses the tourists / disappeared / in the dark.

31. (a) The singer that / the dancer pleases / misunderstood / the question.
The singers that / the dancers please / misunderstood / the question.

(b) The singer that / pleases the dancer / misunderstood / the question.
The singers that / please the dancers / misunderstood / the question.

(c) The singers that / the dancer pleases / misunderstood / the question.
The singer that / the dancers please / misunderstood / the question.

(d) The singers that / please the dancer / misunderstood / the question.
The singer that / pleases the dancers / misunderstood / the question.

32. (a) The scientist that / the inventor entertains / delivered / the products.
The scientists that / the inventors entertain / delivered / the products.

(b) The scientist that / entertains the inventor / delivered / the products.
The scientists that / entertain the inventors / delivered / the products.

(c) The scientists that / the inventor entertains / delivered / the products.
The scientist that / the inventors entertain / delivered / the products.

(d) The scientists that / entertain the inventor / delivered / the products.
The scientist that / entertains the inventors / delivered / the products.

A.3 Experiment 3: sentence stimuli

1. (a) The fundraiser / who welcomed / the helpers of the sponsors / was on / the organising / committee.
   (b) The fundraiser / who welcomed / the helpers of the sponsor / was on / the organising / committee.
   (c) The fundraiser / who welcomed / the helper of the sponsors / was on / the organising / committee.
   (d) The fundraiser / who welcomed / the helper of the sponsor / was on / the organising / committee.
2. (a) The security guard / who identified / the managers of the cleaners / was on / the phone / for some time.
   (b) The security guard / who identified / the managers of the cleaner / was on / the phone / for some time.
   (c) The security guard / who identified / the manager of the cleaners / was on / the phone / for some time.
   (d) The security guard / who identified / the manager of the cleaner / was on / the phone / for some time.
3. (a) The chauffeur / who greeted / the assistants of the politicians / was at / the station's / taxi rank.
   (b) The chauffeur / who greeted / the assistants of the politician / was at / the station's / taxi rank.
   (c) The chauffeur / who greeted / the assistant of the politicians / was at / the station's / taxi rank.
   (d) The chauffeur / who greeted / the assistant of the politician / was at / the station's / taxi rank.
4. (a) The janitor / who advised / the apprentices of the carpenters / was in / the building / this morning.
   (b) The janitor / who advised / the apprentices of the carpenter / was in / the building / this morning.

(c) The janitor / who advised / the apprentice of the carpenters / was in / the building / this morning.

(d) The janitor / who advised / the apprentice of the carpenter / was in / the building / this morning.

5. (a) The secretary / who phoned / the customers of the directors / was on / the train / to the meeting.

   (b) The secretary / who phoned / the customers of the director / was on / the train / to the meeting.

   (c) The secretary / who phoned / the customer of the directors / was on / the train / to the meeting.

   (d) The secretary / who phoned / the customer of the director / was on / the train / to the meeting.

6. (a) The specialist / who contacted / the patients of the doctors / was on / the balcony / relaxing.

   (b) The specialist / who contacted / the patients of the doctor / was on / the balcony / relaxing.

   (c) The specialist / who contacted / the patient of the doctors / was on / the balcony / relaxing.

   (d) The specialist / who contacted / the patient of the doctor / was on / the balcony / relaxing.

7. (a) The buyer / who liked / the supervisors of the builders / was in / the street / during the night.

   (b) The buyer / who liked / the supervisors of the builder / was in / the street / during the night.

   (c) The buyer / who liked / the supervisor of the builders / was in / the street / during the night.

   (d) The buyer / who liked / the supervisor of the builder / was in / the street / during / the night.

8. (a) The contractor / who called / the clients of the architects / was on / the building / site yesterday.

(b) The contractor / who called / the clients of the architect / was on / the building / site yesterday.

(c) The contractor / who called / the client of the architects / was on / the building / site yesterday.

(d) The contractor / who called / the client of the architect / was on / the building / site yesterday.

9. (a) The professor / who examined / the students of the instructors / was in / the university / library.

(b) The professor / who examined / the students of the instructor / was in / the university / library.

(c) The professor / who examined / the student of the instructors / was in / the university / library.

(d) The professor / who examined / the student of the instructor / was in / the university / library.

10. (a) The host / who befriended / the servants of the aristocrats / was at / the surprise / party yesterday.

(b) The host / who befriended / the servants of the aristocrat / was at / the surprise / party yesterday.

(c) The host / who befriended / the servant of the aristocrats / was at / the surprise / party yesterday.

(d) The host / who befriended / the servant of the aristocrat / was at / the surprise / party yesterday.

11. (a) The fan / who understood / the biographers of the singers / was at / the performance / last week.

(b) The fan / who understood / the biographers of the singer / was at / the performance / last week.

(c) The fan / who understood / the biographer of the singers / was at / the performance / last week.

(d) The fan / who understood / the biographer of the singer / was at / the performance / last week.

12. (a) The presenter / who praised / the doubles of the actors / was on / the boat / drinking champagne.

    (b) The presenter / who praised / the doubles of the actor / was on / the boat / drinking champagne.

    (c) The presenter / who praised / the double of the actors / was on / the boat / drinking champagne.

    (d) The presenter / who praised / the double of the actor / was on / the boat / drinking champagne.

13. (a) The volunteer / who helped / the assistants of the designers / was in / the head / office last night.

    (b) The volunteer / who helped / the assistants of the designer / was in / the head / office last night.

    (c) The volunteer / who helped / the assistant of the designers / was in / the head / office last night.

    (d) The volunteer / who helped / the assistant of the designer / was in / the head / office last night.

14. (a) The driver / who transported / the pupils of the teachers / was on / the front / seat in the bus.

    (b) The driver / who transported / the pupils of the teacher / was on / the front / seat in the bus.

    (c) The driver / who transported / the pupil of the teachers / was on / the front / seat in the bus.

    (d) The driver / who transported / the pupil of the teacher / was on / the front / seat in the bus.

15. (a) The editor / who remembered / the visitors of the authors / was on / the plane / to the USA.

    (b) The editor / who remembered / the visitors of the author / was on / the plane / to the USA.

    (c) The editor / who remembered / the visitor of the authors / was on / the plane / to / the USA.

(d) The editor / who remembered / the visitor of the author / was on / the plane / to the USA.

16. (a) The president / who promoted / the bosses of the agents / was on the / yacht in / the Mediterranean.

    (b) The president / who promoted / the bosses of the agent / was on the / yacht in / the Mediterranean.

    (c) The president / who promoted / the boss of the agents / was on the / yacht in / the Mediterranean.

    (d) The president / who promoted / the boss of the agent / was on the / yacht in / the Mediterranean.

17. (a) The medic / who bandaged / the supporters of the players / was at / the scene / very rapidly.

    (b) The medic / who bandaged / the supporters of the player / was at / the scene / very rapidly.

    (c) The medic / who bandaged / the supporter of the players / was at / the scene / very rapidly.

    (d) The medic / who bandaged / the supporter of the player / was at / the scene / very rapidly.

18. (a) The administrator / who monitored / the landlords of the tenants / was on / the bus / to the city centre.

    (b) The administrator / who monitored / the landlords of the tenant / was on / the bus / to the city centre.

    (c) The administrator / who monitored / the landlord of the tenants / was on / the bus / to the city centre.

    (d) The administrator / who monitored / the landlord of the tenant / was on / the bus / to the city centre.

19. (a) The cook / who met / the friends of the waiters / was on / the stairs / for a while.

    (b) The cook / who met / the friends of the waiter / was on / the stairs / for a while.

(c) The cook / who met / the friend of the waiters / was on / the stairs / for a while.

(d) The cook / who met / the friend of the waiter / was on / the stairs / for a while.

20. (a) The artist / who liked / the guests of the painters / was at / the party / for a long time.

(b) The artist / who liked / the guests of the painter / was at / the party / for a long time.

(c) The artist / who liked / the guest of the painters / was at / the party / for a long time.

(d) The artist / who liked / the guest of the painter / was at / the party / for a long time.

21. (a) The farmer / who knew / the relatives of the peasants / was on / the radio / show yesterday.

(b) The farmer / who knew / the relatives of the peasant / was on / the radio / show yesterday.

(c) The farmer / who knew / the relative of the peasants / was on / the radio / show yesterday.

(d) The farmer / who knew / the relative of the peasant / was on / the radio / show yesterday.

22. (a) The trainer / who blamed / the sponsors of the footballers / was in / the stadium / all day.

(b) The trainer / who blamed / the sponsors of the footballer / was in / the stadium / all day.

(c) The trainer / who blamed / the sponsor of the footballers / was in / the stadium / all day.

(d) The trainer / who blamed / the sponsor of the footballer / was in / the stadium / all day.

23. (a) The constable / who observed / the accomplices of the burglars / was on / the lookout / for a suspect.

(b) The constable / who observed / the accomplices of the burglar / was on / the lookout / for a suspect.

(c) The constable / who observed / the accomplice of the burglars / was on / the lookout / for a suspect.

(d) The constable / who observed / the accomplice of the burglar / was on / the lookout / for a suspect.

24. (a) The mentor / who motivated / the colleagues of the scientists / was on / the university / committee.

(b) The mentor / who motivated / the colleagues of the scientist / was on / the university / committee.

(c) The mentor / who motivated / the colleague of the scientists / was on / the university / committee.

(d) The mentor / who motivated / the colleague of the scientist / was on / the university / committee.

25. (a) The coach / who trained / the officers of the soldiers / was on the / list for / a promotion.

(b) The coach / who trained / the officers of the soldier / was on the / list for / a promotion.

(c) The coach / who trained / the officer of the soldiers / was on the / list for / a promotion.

(d) The coach / who trained / the officer of the soldier / was on the / list for / a promotion.

26. (a) The delegate / who assisted / the bodyguards of the celebrities / was on / the long / list for a ticket.

(b) The delegate / who assisted / the bodyguards of the celebrity / was on / the long / list for a ticket.

(c) The delegate / who assisted / the bodyguard of the celebrities / was on / the long / list for a ticket.

(d) The delegate / who assisted / the bodyguard of the celebrity / was on / the long / list for a ticket.

27. (a) The investigator / who questioned / the lawyers of the activists / was on / the news / two days ago.
    (b) The investigator / who questioned / the lawyers of the activist / was on / the news / two days ago.
    (c) The investigator / who questioned / the lawyer of the activists / was on / the news / two days ago.
    (d) The investigator / who questioned / the lawyer of the activist / was on / the news / two days ago.

28. (a) The official / who informed / the advisors of the plaintiffs / was in / the company / board meeting.
    (b) The official / who informed / the advisors of the plaintiff / was in / the company / board meeting.
    (c) The official / who informed / the advisor of the plaintiffs / was in / the company / board meeting.
    (d) The official / who informed / the advisor of the plaintiff / was in / the company / board meeting.

29. (a) The terrorist / who kidnapped / the associates of the entrepreneurs / was in / the house / in Manchester.
    (b) The terrorist / who kidnapped / the associates of the entrepreneur / was in / the house / in Manchester.
    (c) The terrorist / who kidnapped / the associate of the entrepreneurs / was in / the house / in Manchester.
    (d) The terrorist / who kidnapped / the associate of the entrepreneur / was in / the house / in Manchester.

30. (a) The tourist / who thanked / the trainees of the translators / was on / the trip / of a life time.
    (b) The tourist / who thanked / the trainees of the translator / was on / the trip / of a life time.
    (c) The tourist / who thanked / the trainee of the translators / was on / the trip / of a life time.

(d) The tourist / who thanked / the trainee of the translator / was on / the trip / of a life time.

31. (a) The judge / who supported / the victims of the criminals / was in / the very / old court room.

    (b) The judge / who supported / the victims of the criminal / was in / the very / old court room.

    (c) The judge / who supported / the victim of the criminals / was in / the very / old court room.

    (d) The judge / who supported / the victim of the criminal / was in / the very / old court room.

32. (a) The superintendent / who met / the employees of the proprietors / was on / the management / committee.

    (b) The superintendent / who met / the employees of the proprietor / was on / the management / committee.

    (c) The superintendent / who met / the employee of the proprietors / was on / the management / committee.

    (d) The superintendent / who met / the employee of the proprietor / was on / the management / committee.

33. (a) The citizen / who sued / the followers of the extremists / was on / the TV show / last night.

    (b) The citizen / who sued / the followers of the extremist / was on / the TV show / last night.

    (c) The citizen / who sued / the follower of the extremists / was on / the TV show / last night.

    (d) The citizen / who sued / the follower of the extremist / was on / the TV show / last night.

34. (a) The psychologist / who visited / the nurses of the veterans / was on / the verge / of giving up.

    (b) The psychologist / who visited / the nurses of the veteran / was on / the verge / of giving up.

(c) The psychologist / who visited / the nurse of the veterans / was on / the verge / of giving up.

(d) The psychologist / who visited / the nurse of the veteran / was on / the verge / of giving up.

35. (a) The butler / who fired / the maids of the millionaires / was in / the gardens / of the mansion.

(b) The butler / who fired / the maids of the millionaire / was in / the gardens / of the mansion.

(c) The butler / who fired / the maid of the millionaires / was in / the gardens / of the mansion.

(d) The butler / who fired / the maid of the millionaire / was in / the gardens / of the mansion.

36. (a) The minister / who rewarded / the traitors of the spies / was on / the advisory / panel yesterday.

(b) The minister / who rewarded / the traitors of the spy / was on / the advisory / panel yesterday.

(c) The minister / who rewarded / the traitor of the spies / was on / the advisory / panel yesterday.

(d) The minister / who rewarded / the traitor of the spy / was on / the advisory / panel yesterday.

37. (a) The participant / who contacted / the collaborators of the researchers / was in / the expensive / laboratory.

(b) The participant / who contacted / the collaborators of the researcher / was in / the expensive / laboratory.

(c) The participant / who contacted / the collaborator of the researchers / was in / the expensive / laboratory.

(d) The participant / who contacted / the collaborator of the researcher / was in / the expensive / laboratory.

38. (a) The surgeon / who disliked / the consultants of the pharmacists / was in / the operating / theatre.

(b) The surgeon / who disliked / the consultants of the pharmacist / was in / the operating / theatre.

(c) The surgeon / who disliked / the consultant of the pharmacists / was in / the operating / theatre.

(d) The surgeon / who disliked / the consultant of the pharmacist / was in / the operating / theatre.

39. (a) The boxer / who recognised / the representatives of the promoters / was on / the special / new diet.

(b) The boxer / who recognised / the representatives of the promoter / was on / the special / new diet.

(c) The boxer / who recognised / the representative of the promoters / was on / the special / new diet.

(d) The boxer / who recognised / the representative of the promoter / was on / the special / new diet.

40. (a) The volunteer / who approached / the accountants of the tycoons / was on / the board / two years ago.

(b) The volunteer / who approached / the accountants of the tycoon / was on / the board / two years ago.

(c) The volunteer / who approached / the accountant of the tycoons / was on / the board / two years ago.

(d) The volunteer / who approached / the accountant of the tycoon / was on / the board / two years ago.

A.4 Experiment 4: sentence stimuli

1. (a) The security guard / who walked to / the cleaners of the managers / was on / the phone / arguing.

(b) The security guard / who walked to / the cleaners of the manager / was on / the phone / arguing.

(c) The security guard / who walked to / the cleaner of the managers / was on / the phone / arguing.

(d) The security guard / who walked to / the cleaner of the manager / was on / the phone / arguing.

2. (a) The chauffeur / who left with / the assistants of the politicians / was in / the city / centre.

   (b) The chauffeur / who left with / the assistants of the politician / was in / the city / centre.

   (c) The chauffeur / who left with / the assistant of the politicians / was in / the city / centre.

   (d) The chauffeur / who left with / the assistant of the politician / was in / the city / centre.

3. (a) The janitor / who spoke to / the apprentices of the carpenters / was on / the way / to the venue.

   (b) The janitor / who spoke to / the apprentices of the carpenter / was on / the way / to the venue.

   (c) The janitor / who spoke to / the apprentice of the carpenters / was on / the way / to the venue.

   (d) The janitor / who spoke to / the apprentice of the carpenter / was on / the way / to the venue.

4. (a) The secretary / who argued with / the customers of the directors / was on / the train / to the meeting.

   (b) The secretary / who argued with / the customers of the director / was on / the train / to the meeting.

   (c) The secretary / who argued with / the customer of the directors / was on / the train / to the meeting.

   (d) The secretary / who argued with / the customer of the director / was on / the train / to the meeting.

5. (a) The artist / who smiled at / the patients of the doctors / was on / the balcony / relaxing.

   (b) The artist / who smiled at / the patients of the doctor / was on / the balcony / relaxing.

(c) The artist / who smiled at / the patient of the doctors / was on / the balcony / relaxing.

(d) The artist / who smiled at / the patient of the doctor / was on / the balcony relaxing.

6. (a) The buyer / who listened to / the supervisors of the builders / was in / the street / late at night.

   (b) The buyer / who listened to / the supervisors of the builder / was in / the street / late at night.

   (c) The buyer / who listened to / the supervisor of the builders / was in / the street / late at night.

   (d) The buyer / who listened to / the supervisor of the builder / was in / the street / late at night.

7. (a) The contractor / who shouted at / the plumbers of the architects / was on / the platform / yesterday.

   (b) The contractor / who shouted at / the plumbers of the architect / was on / the platform / yesterday.

   (c) The contractor / who shouted at / the plumber of the architects / was on / the platform / yesterday.

   (d) The contractor / who shouted at / the plumber of the architect / was on / the platform / yesterday.

8. (a) The professor / who forgot about / the students of the instructors / was on / the ladder / in the library.

   (b) The professor / who forgot about / the students of the instructor / was on / the ladder / in the library.

   (c) The professor / who forgot about / the student of the instructors / was on / the ladder / in the library.

   (d) The professor / who forgot about / the student of the instructor / was on / the ladder / in the library.

9. (a) The host / who agreed with / the associates of the organizers / was on / the edge / of the cliff.

(b) The host / who agreed with / the associates of the organizer / was on / the edge / of the cliff.

(c) The host / who agreed with / the associate of the organizers / was on / the edge / of the cliff.

(d) The host / who agreed with / the associate of the organizer / was on / the edge / of the cliff.

10. (a) The fan / who stared at / the biographers of the actresses / was on / the podium / with the idol.

(b) The fan / who stared at / the biographers of the actress / was on / the podium / with the idol.

(c) The fan / who stared at / the biographer of the actresses / was on / the podium / with the idol.

(d) The fan / who stared at / the biographer of the actress / was on / the podium / with the idol.

11. (a) The presenter / who met with / the doubles of the actors / was on / the boat / drinking champagne.

(b) The presenter / who met with / the doubles of the actor / was on / the boat / drinking champagne.

(c) The presenter / who met with / the double of the actors / was on / the boat / drinking champagne.

(d) The presenter / who met with / the double of the actor / was on / the boat / drinking champagne.

12. (a) The volunteer / who waited for / the assistants of the designers / was in / the head / office.

(b) The volunteer / who waited for / the assistants of the designer / was in / the head / office.

(c) The volunteer / who waited for / the assistant of the designers / was in / the head / office.

(d) The volunteer / who waited for / the assistant of the designer / was in / the head / office.

13. (a) The driver / who joked about / the pupils of the teachers / was on / the seat / in the bus.
    (b) The driver / who joked about / the pupils of the teacher / was on / the seat / in the bus.
    (c) The driver / who joked about / the pupil of the teachers / was on / the seat / in the bus.
    (d) The driver / who joked about / the pupil of the teacher / was on / the seat / in the bus.
14. (a) The editor / who chatted with / the visitors of the authors / was on / the plane / to the US.
    (b) The editor / who chatted with / the visitors of the author / was on / the plane / to the US.
    (c) The editor / who chatted with / the visitor of the authors / was on / the plane / to the US.
    (d) The editor / who chatted with / the visitor of the author / was on / the plane / to the US.
15. (a) The president / who negotiated with / the bosses of the agents / was on / the yacht / celebrating.
    (b) The president / who negotiated with / the bosses of the agent / was on / the yacht / celebrating.
    (c) The president / who negotiated with / the boss of the agents / was on / the yacht / celebrating.
    (d) The president / who negotiated with / the boss of the agent / was on / the yacht /celebrating.
16. (a) The medic / who cared for / the supporters of the players / was on / the scooter / to the hospital.
    (b) The medic / who cared for / the supporters of the player / was on / the scooter / to the hospital.
    (c) The medic / who cared for / the supporter of the players / was on / the scooter / to the hospital.

(d) The medic / who cared for / the supporter of the player / was on / the scooter / to the hospital.

17. (a) The administrator / who communicated with / the landlords of the tenants / was on / the bus / to work.

    (b) The administrator / who communicated with / the landlords of the tenant / was on / the bus / to work.

    (c) The administrator / who communicated with / the landlord of the tenants / was on / the bus / to work.

    (d) The administrator / who communicated with / the landlord of the tenant / was on / the bus / to work.

18. (a) The cook / who looked after / the friends of the waiters / was on / the stairs / to the bar.

    (b) The cook / who looked after / the friends of the waiter / was on / the stairs / to the bar.

    (c) The cook / who looked after / the friend of the waiters / was on / the stairs / to the bar.

    (d) The cook / who looked after / the friend of the waiter / was on / the stairs / to the bar.

19. (a) The artist / who eavesdropped on / the guests of the painters / was at / the party / for a long time.

    (b) The artist / who eavesdropped on / the guests of the painter / was at / the party / for a long time.

    (c) The artist / who eavesdropped on / the guest of the painters / was at / the party / for a long time.

    (d) The artist / who eavesdropped on / the guest of the painter / was at / the party / for a long time.

20. (a) The farmer / who hid from / the relatives of the peasants / was on / the radio / show yesterday.

    (b) The farmer / who hid from / the relatives of the peasant / was on / the radio / show yesterday.

(c) The farmer / who hid from / the relative of the peasants / was on / the radio / show yesterday.

(d) The farmer / who hid from / the relative of the peasant / was on / the radio / show yesterday.

21. (a) The policeman / who fought with / the accomplices of the burglars / was on / the lookout / for a suspect.

(b) The policeman / who fought with / the accomplices of the burglar / was on / the lookout / for a suspect.

(c) The policeman / who fought with / the accomplice of the burglars / was on / the lookout / for a suspect.

(d) The policeman / who fought with / the accomplice of the burglar / was on / the lookout / for a suspect.

22. (a) The mentor / who disapproved of / the colleagues of the scientists / was on / the university / budgeting committee.

(b) The mentor / who disapproved of / the colleagues of the scientist / was on / the university / budgeting committee.

(c) The mentor / who disapproved of / the colleague of the scientists / was on / the university / budgeting committee.

(d) The mentor / who disapproved of / the colleague of the scientist / was on / the university / budgeting committee.

23. (a) The trainer / who screamed at / the officers of the soldiers / was on / the list / for a promotion.

(b) The trainer / who screamed at / the officers of the soldier / was on / the list / for a promotion.

(c) The trainer / who screamed at / the officer of the soldiers / was on / the list / for a promotion.

(d) The trainer / who screamed at / the officer of the soldier / was on / the list / for a promotion.

24. (a) The delegate / who apologized to / the bodyguards of the celebrities / was on / the waiting / list for a ticket.

(b) The delegate / who apologized to / the bodyguard of the celebrities / was on / the waiting / list for a ticket.

(c) The delegate / who apologized to / the bodyguards of the celebrity / was on / the waiting / list for a ticket.

(d) The delegate / who apologized to / the bodyguard of the celebrity / was on / the waiting / list for a ticket.

25. (a) The investigator / who dealt with / the lawyers of the activists / was on / the news / last night.

(b) The investigator / who dealt with / the lawyers of the activist / was on / the news / last night.

(c) The investigator / who dealt with / the lawyer of the activists / was on / the news / last night.

(d) The investigator / who dealt with / the lawyer of the activist / was on / the news / last night.

26. (a) The official / who turned to / the advisors of the plaintiffs / was in / the board / meeting.

(b) The official / who turned to / the advisors of the plaintiff / was in / the board / meeting.

(c) The official / who turned to / the advisor of the plaintiffs / was in / the board / meeting.

(d) The official / who turned to / the advisor of the plaintiff / was in / the board / meeting.

27. (a) The tourist / who travelled with / the trainees of the translators / was on / the trip / of a life time.

(b) The tourist / who travelled with / the trainees of the translator / was on / the trip / of a life time.

(c) The tourist / who travelled with / the trainee of the translators / was on / the trip / of a life time.

(d) The tourist / who travelled with / the trainee of the translator / was on / the trip / of a life time.

28. (a) The judge / who worried about / the victims of the criminals / was in / the old / court room.

    (b) The judge / who worried about / the victims of the criminal / was in / the old / court room.

    (c) The judge / who worried about / the victim of the criminals / was in / the old / court room.

    (d) The judge / who worried about / the victim of the criminal / was in / the old / court room.

29. (a) The father / who wrote to / the workers of the proprietors / was on / the parents' / committee.

    (b) The father / who wrote to / the workers of the proprietor / was on / the parents' / committee.

    (c) The father / who wrote to / the worker of the proprietors / was on / the parents' / committee.

    (d) The father / who wrote to / the worker of the proprietor / was on / the parents' /committee.

30. (a) The citizen / who appealed to / the followers of the extremists / was on / TV for the / first time.

    (b) The citizen / who appealed to / the followers of the extremist / was on / TV for the / first time.

    (c) The citizen / who appealed to / the follower of the extremists / was on / TV for the / first time.

    (d) The citizen / who appealed to / the follower of the extremist / was on / TV for the / first time.

31. (a) The psychologist / who asked for / the nurses of the veterans / was on / the verge / of giving up.

    (b) The psychologist / who asked for / the nurses of the veteran / was on / the verge / of giving up.

    (c) The psychologist / who asked for / the nurse of the veterans / was on / the verge / of giving up.

(d) The psychologist / who asked for / the nurse of the veteran / was on / the verge / of giving up.

32. (a) The butler / who thought about / the maids of the princes / was in / the gardens / of the palace.
    (b) The butler / who thought about / the maids of the prince / was in / the gardens / of the palace.
    (c) The butler / who thought about / the maid of the princes / was in / the gardens / of the palace.
    (d) The butler / who thought about / the maid of the prince / was in / the gardens / of the palace.

33. (a) The minister / who complained about / the traitors of the spies / was on / the advisory / panel yesterday.
    (b) The minister / who complained about / the traitors of the spy / was on / the advisory / panel yesterday.
    (c) The minister / who complained about / the traitor of the spies / was on / the advisory / panel yesterday.
    (d) The minister / who complained about / the traitor of the spy / was on / the advisory / panel yesterday.

34. (a) The surgeon / who paid for / the consultants of the pharmacists / was in / the operating / theatre.
    (b) The surgeon / who paid for / the consultants of the pharmacist / was in / the operating / theatre.
    (c) The surgeon / who paid for / the consultant of the pharmacists / was in / the operating / theatre.
    (d) The surgeon / who paid for / the consultant of the pharmacist / was in / the operating / theatre.

35. (a) The boxer / who cooperated with / the representatives of the promoters / was on / a special / new diet.
    (b) The boxer / who cooperated with / the representatives of the promoter / was on / a special / new diet.

(c) The boxer / who cooperated with / the representative of the promoters / was on / a special / new diet.

(d) The boxer / who cooperated with / the representative of the promoter / was on / a special / new diet.

36. (a) The volunteer / who worked for / the accountants of the millionaires / was on / the dole / last year.

(b) The volunteer / who worked for / the accountants of the millionaire / was on / the dole / last year.

(c) The volunteer / who worked for / the accountant of the millionaires / was on / the dole / last year.

(d) The volunteer / who worked for / the accountant of the millionaire / was on / the dole / last year.

A.5 Experiment 5: sentence stimuli

1. (a) The cook understood that the lady / who claimed that the pensioner seemed healthy / has been / enjoying / the meal.

(b) The cook understood that the lady / who claimed that the pensioners seemed healthy / has been / enjoying / the meal.

(c) The cook understood that the lady / who was sitting behind the healthy pensioner / has been / enjoying / the meal.

(d) The cook understood that the lady / who was sitting behind the healthy pensioners / has been / enjoying / the meal.

2. (a) The director noticed that the worker / who heard that the assistant became sick / has been / lazy at / work lately.

(b) The director noticed that the worker / who heard that the assistants became sick / has been / lazy at / work lately.

(c) The director noticed that the worker / who was caring for the sick assistant / has been / lazy at / work lately.

(d) The director noticed that the worker / who was caring for the sick assistants / has been / lazy at / work lately.

3. (a) The manager saw that the banker / who forgot that the client appeared angry / has been / nervous / and tired.
   (b) The manager saw that the banker / who forgot that the clients appeared angry / has been / nervous / and tired.
   (c) The manager saw that the banker / who was talking to the angry client / has been / nervous / and tired.
   (d) The manager saw that the banker / who was talking to the angry clients / has been / nervous / and tired.
4. (a) The professor regretted that the student / who noticed that the lecturer looked confused / has been / quiet for / a long time.
   (b) The professor regretted that the student / who noticed that the lecturers looked confused / has been / quiet for / a long time.
   (c) The professor regretted that the student / who was standing behind the confused lecturer / has been / quiet for / a long time.
   (d) The professor regretted that the student / who was standing behind the confused lecturers / has been / quiet for / a long time.
5. (a) The player remembered that the coach / who realised that the doctor remained silent / has been / ambitious / and prepared.
   (b) The player remembered that the coach / who realised that the doctors remained silent / has been / ambitious / and prepared.
   (c) The player remembered that the coach / who was staring at the silent doctor / has been / ambitious / and prepared.
   (d) The player remembered that the coach / who was staring at the silent doctors / has been / ambitious / and prepared.
6. (a) The mother observed that the neighbour / who confessed that the visitor arrived drunk / has been / envious / about the gifts.
   (b) The mother observed that the neighbour / who confessed that the visitors arrived drunk / has been / envious / about the gifts.
   (c) The mother observed that the neighbour / who was looking after the drunk visitor / has been / envious / about the gifts.

(d) The mother observed that the neighbour / who was looking after the drunk visitors / has been / envious / about the gifts.

7. (a) The aunt remarked that the niece / who admitted that the teacher reacted upset / has been / anxious / and sweaty.

   (b) The aunt remarked that the niece / who admitted that the teachers reacted upset / has been / anxious / and sweaty.

   (c) The aunt remarked that the niece / who was waiting for the upset teacher / has been / anxious / and sweaty.

   (d) The aunt remarked that the niece / who was waiting for the upset teachers / has been / anxious / and sweaty.

8. (a) The engineer reported that the scientist / who observed that the participant stayed calm / has been / professional / and objective.

   (b) The engineer reported that the scientist / who observed that the participants stayed calm / has been / professional / and objective.

   (c) The engineer reported that the scientist / who was meeting with the calm participant / has been / professional / and objective.

   (d) The engineer reported that the scientist / who was meeting with the calm participants / has been / professional / and objective.

9. (a) The plumber wrote that the tenant / who said that the landlord appeared busy / has been / helpful / and friendly.

   (b) The plumber wrote that the tenant / who said that the landlords appeared busy / has been / helpful / and friendly.

   (c) The plumber wrote that the tenant / who was talking with the busy landlord / has been / helpful / and friendly.

   (d) The plumber wrote that the tenant / who was talking with the busy landlords / has been / helpful / and friendly.

10. (a) The cleaner noted that the janitor / who complained that the porter responded slowly / has been / loud during / the night.

    (b) The cleaner noted that the janitor / who complained that the porters responded slowly / has been / loud during / the night.

(c) The cleaner noted that the janitor / who was quarrelling with the slow porter / has been / loud during / the night.

(d) The cleaner noted that the janitor / who was quarrelling with the slow porters / has been / loud during / the night.

11. (a) The surgeon realized that the patient / who denied that the nurse cleaned energetically / has been / demanding / and annoying.

(b) The surgeon realized that the patient / who denied that the nurses cleaned energetically / has been / demanding / and annoying.

(c) The surgeon realized that the patient / who was sniffing at the energetic nurse / has been / demanding / and annoying.

(d) The surgeon realized that the patient / who was sniffing at the energetic nurses / has been / demanding / and annoying.

12. (a) The electrician read that the mechanic / who replied that the carpenter fell sick / has been / helpful / and considerate.

(b) The electrician read that the mechanic / who replied that the carpenters fell sick / has been / helpful / and considerate.

(c) The electrician read that the mechanic / who was drinking with the sickly carpenter / has been / helpful / and considerate.

(d) The electrician read that the mechanic / who was drinking with the sickly carpenters / has been / helpful / and considerate.

13. (a) The actor heard that the model / who confirmed that the agent became rich / has been / stupid and / very naive.

(b) The actor heard that the model / who confirmed that the agents became rich / has been / stupid and / very naive.

(c) The actor heard that the model / who was dining with the rich agent / has been / stupid and / very naive.

(d) The actor heard that the model / who was dining with the rich agents / has been / stupid and / very naive.

14. (a) The singer lied that the guitarist / who whispered that the drummer acted weirdly / has been / drunk and / confused.

(b) The singer lied that the guitarist / who whispered that the drummers acted weirdly / has been / drunk and / confused.

(c) The singer lied that the guitarist / who was partying with the weird drummer / has been / drunk and / confused.

(d) The singer lied that the guitarist / who was partying with the weird drummers / has been / drunk and / confused.

15. (a) The lawyer mentioned that the judge / who decided that the offender looked guilty / has been / strict but / very fair.

    (b) The lawyer mentioned that the judge / who decided that the offenders looked guilty / has been / strict but / very fair.

    (c) The lawyer mentioned that the judge / who was meeting with the guilty offender / has been / strict but / very fair.

    (d) The lawyer mentioned that the judge / who was meeting with the guilty offenders / has been / strict but / very fair.

16. (a) The officer thought that the guard / who heard that the prisoner sounded cruel / has been / judgemental / and prejudiced.

    (b) The officer thought that the guard / who heard that the prisoners sounded cruel / has been / judgemental / and prejudiced.

    (c) The officer thought that the guard / who was dealing with the cruel prisoner / has been / judgemental / and prejudiced.

    (d) The officer thought that the guard / who was dealing with the cruel prisoners / has been / judgemental / and prejudiced.

17. (a) The painter reported that the artist / who revealed that the apprentice arrived sweaty / has been / supportive / and very helpful.

    (b) The painter reported that the artist / who revealed that the apprentices arrived sweaty / has been / supportive / and very helpful.

    (c) The painter reported that the artist / who was sketching with the sweaty apprentice / has been / supportive / and very helpful.

    (d) The painter reported that the artist / who was sketching with the sweaty apprentices / has been / supportive / and very helpful.

18. (a) The boss warned that the supervisor / who discovered that the trainee finished fast / has been / late and / stressed.

    (b) The boss warned that the supervisor / who discovered that the trainees finished fast / has been / late and / stressed.

    (c) The boss warned that the supervisor / who was working with the fast trainee / has been / late and / stressed.

    (d) The boss warned that the supervisor / who was working with the fast trainees / has been / late and / stressed.

19. (a) The administrator declared that the technician / who worried that the specialist felt important / has been / incompetent / and unprepared.

    (b) The administrator declared that the technician / who worried that the specialists felt important / has been / incompetent / and unprepared.

    (c) The administrator declared that the technician / who was paying for the important specialist / has been / incompetent / and unprepared.

    (d) The administrator declared that the technician / who was paying for the important specialists / has been / incompetent / and unprepared.

20. (a) The researcher moaned that the secretary / who indicated that the participant seemed concerned / has been / nosy and / inquisitive.

    (b) The researcher moaned that the secretary / who indicated that the participants seemed concerned / has been / nosy and / inquisitive.

    (c) The researcher moaned that the secretary / who was talking with the concerned participant / has been / nosy and / inquisitive.

    (d) The researcher moaned that the secretary / who was talking with the concerned participants / has been / nosy and / inquisitive.

21. (a) The host overheard that the driver / who mentioned that the bodyguard entered quickly / has been / efficient / and capable.

    (b) The host overheard that the driver / who mentioned that the bodyguards entered quickly / has been / efficient / and capable.

    (c) The host overheard that the driver / who was waiting for the quick bodyguard / has been / efficient / and capable.

(d) The host overheard that the driver / who was waiting for the quick bodyguards / has been / efficient / and capable.

22. (a) The biologist ignored that the chemist / who approved that the collaborator submitted punctually / has been / forgetful / and chaotic.

(b) The biologist ignored that the chemist / who approved that the collaborators submitted punctually / has been / forgetful / and chaotic.

(c) The biologist ignored that the chemist / who was collaborating with the punctual collaborator / has been / forgetful / and chaotic.

(d) The biologist ignored that the chemist / who was collaborating with the punctual collaborators / has been / forgetful / and chaotic.

23. (a) The supporter discovered that the wrestler / who ensured that the rival surrendered quickly / has been / dishonest / and deceitful.

(b) The supporter discovered that the wrestler / who ensured that the rivals surrendered quickly / has been / dishonest / and deceitful.

(c) The supporter discovered that the wrestler / who was competing with the quick rival / has been / dishonest / and deceitful.

(d) The supporter discovered that the wrestler / who was competing with the quick rivals / has been / dishonest / and deceitful.

24. (a) The detective observed that the robber / who agreed that the bandit acted carelessly / has been / obsessed / by fear.

(b) The detective observed that the robber / who agreed that the bandits acted carelessly / has been / obsessed / by fear.

(c) The detective observed that the robber / who was fooling with the careless bandit / has been / obsessed / by fear.

(d) The detective observed that the robber / who was fooling with the careless bandits / has been / obsessed / by fear.

25. (a) The collector believed that the customer / who remarked that the trader helped keenly / has been / honest and / truthful.

(b) The collector believed that the customer / who remarked that the traders helped keenly / has been / honest and / truthful.

(c) The collector believed that the customer / who was haggling with the keen trader / has been / honest and / truthful.

(d) The collector believed that the customer / who was haggling with the keen traders / has been / honest and / truthful.

26. (a) The soldier argued that the general / who reported that the civilian exercised reluctantly / has been / impatient / and strict.

(b) The soldier argued that the general / who reported that the civilians exercised reluctantly / has been / impatient / and strict.

(c) The soldier argued that the general / who was exercising with the reluctant civilian / has been / impatient / and strict.

(d) The soldier argued that the general / who was exercising with the reluctant civilians / has been / impatient / and strict.

27. (a) The potter doubted that the craftsman / who lamented that the sculptor worked carelessly / has been / competent / and careful.

(b) The potter doubted that the craftsman / who lamented that the sculptors worked carelessly / has been / competent / and careful.

(c) The potter doubted that the craftsman / who was working with the careless sculptor / has been / competent / and careful.

(d) The potter doubted that the craftsman / who was working with the careless sculptors / has been / competent / and careful.

28. (a) The astronaut agreed that the pilot / who confirmed that the stewardess disappeared discreetly / has been / correct / and honest.

(b) The astronaut agreed that the pilot / who confirmed that the stewardesses disappeared discreetly / has been / correct / and honest.

(c) The astronaut agreed that the pilot / who was flying with the discreet stewardess / has been / correct / and honest.

(d) The astronaut agreed that the pilot / who was flying with the discreet stewardesses / has been / correct / and honest.

29. (a) The warden sensed that the interrogator / who assumed that the inmate answered politely / has been / tired and / sleepy.

(b) The warden sensed that the interrogator / who assumed that the inmates answered politely / has been / tired and / sleepy.

(c) The warden sensed that the interrogator / who was siding with the polite inmate / has been / tired and / sleepy.

(d) The warden sensed that the interrogator / who was siding with the polite inmates / has been / tired and / sleepy.

30. (a) The cook disliked that the waiter / who agreed that the scout smelled funny / has been / working / all night.

(b) The cook disliked that the waiter / who agreed that the scouts smelled funny / has been / working / all night.

(c) The cook disliked that the waiter / who was hiking with the smelly scout / has been / working / all night.

(d) The cook disliked that the waiter / who was hiking with the smelly scouts / has been / working / all night.

31. (a) The ranger figured that the trapper / who discovered that the hunter acted dangerously / has been / living / in the forest.

(b) The ranger figured that the trapper / who discovered that the hunters acted dangerously / has been / living / in the forest.

(c) The ranger figured that the trapper / who was searching for the dangerous hunter / has been / living / in the forest.

(d) The ranger figured that the trapper / who was searching for the dangerous hunters / has been / living / in the forest.

32. (a) The tourist guide guessed that the bus driver / who assured that the traveller arrived promptly / has been / on a deserved / holiday.

(b) The tourist guide guessed that the bus driver / who assured that the travellers arrived promptly / has been / on a deserved / holiday.

(c) The tourist guide guessed that the bus driver / who was connecting with the prompt traveller / has been / on a deserved / holiday.

(d) The tourist guide guessed that the bus driver / who was connecting with the prompt travellers / has been / on a deserved / holiday.

33. (a) The passenger estimated that the captain / who recollected that the artist performed poorly / has been / away for / two weeks.

(b) The passenger estimated that the captain / who recollected that the artists performed poorly / has been / away for / two weeks.

(c) The passenger estimated that the captain / who was leaving with the poor artist / has been / away for / two weeks.

(d) The passenger estimated that the captain / who was leaving with the poor artists / has been / away for / two weeks.

34. (a) The millionaire suspected that the consultant / who speculated that the butler cheated secretly / has been / tactless / and foolish.

(b) The millionaire suspected that the consultant / who speculated that the butlers cheated secretly / has been / tactless / and foolish.

(c) The millionaire suspected that the consultant / who was welcoming the secretive butler / has been / tactless / and foolish.

(d) The millionaire suspected that the consultant / who was welcoming the secretive butlers / has been / tactless / and foolish.

35. (a) The diver inferred that the instructor / who saw that the surfer jumped skillfully / has been / attentive / and considerate.

(b) The diver inferred that the instructor / who saw that the surfers jumped skillfully / has been / attentive / and considerate.

(c) The diver inferred that the instructor / who was focussing on the skillful surfer / has been / attentive / and considerate.

(d) The diver inferred that the instructor / who was focussing on the skillful surfers / has been / attentive / and considerate.

36. (a) The editor knew that the journalist / who reckoned that the politician behaved irresponsibly / has been / the source / of the news.

(b) The editor knew that the journalist / who reckoned that the politicians behaved irresponsibly / has been / the source / of the news.

(c) The editor knew that the journalist / who was dining with the irresponsible politician / has been / the source / of the news.

(d) The editor knew that the journalist / who was dining with the irresponsible politicians / has been / the source / of the news.

37. (a) The presenter acknowledged that the photographer / who professed that the journalist talked convincingly / has been / awarded / the prize.

(b) The presenter acknowledged that the photographer / who professed that the journalists talked convincingly / has been / awarded / the prize.

(c) The presenter acknowledged that the photographer / who was chatting with the convincing journalist / has been / awarded / the prize.

(d) The presenter acknowledged that the photographer / who was chatting with the convincing journalists / has been / awarded / the prize.

38. (a) The mother pointed out that the nanny / who ensured that the boy behaved well / has been / a very experienced / teacher.

(b) The mother pointed out that the nanny / who ensured that the boys behaved well / has been / a very experienced / teacher.

(c) The mother pointed out that the nanny / who was supervising the good boy / has been / a very experienced / teacher.

(d) The mother pointed out that the nanny / who was supervising the good boys / has been / a very experienced / teacher.

39. (a) The breeder accepted that the vet / who presumed that the farmer helped kindly / has been / given all / the money.

(b) The breeder accepted that the vet / who presumed that the farmers helped kindly / has been / given all / the money.

(c) The breeder accepted that the vet / who was driving past the kind farmer / has been / given all / the money.

(d) The breeder accepted that the vet / who was driving past the kind farmers / has been / given all / the money.

40. (a) The author understood that the editor / who recommended that the reviewer proofread thoroughly / has been / critical / of the manuscript.

(b) The author understood that the editor / who recommended that the reviewers proofread thoroughly / has been / critical / of the manuscript.

(c) The author understood that the editor / who was proofreading with the thorough reviewer / has been / critical / of the manuscript.

(d) The author understood that the editor / who was proofreading with the thorough reviewers / has been / critical / of the manuscript.

A.6 Experiment 6: sentence stimuli

1. (a) After Adam phoned the clerk of the manager / has to / finish the / paperwork.

   (b) After Adam phoned the clerk of the managers / has to / finish the / paperwork.

   (c) After Adam phoned, the clerk of the manager / has to / finish the / paperwork.

   (d) After Adam phoned, the clerk of the managers / has to / finish the / paperwork.

2. (a) While Sally assisted the lawyer of the client / has to / find the / documents.

   (b) While Sally assisted the lawyer of the clients / has to / find the / documents.

   (c) While Sally assisted, the lawyer of the client / has to / find the / documents.

   (d) While Sally assisted, the lawyer of the clients / has to / find the / documents.

3. (a) When Frank helped the supplier of the grocer / has to / ask for / more money.

   (b) When Frank helped the supplier of the grocers / has to / ask for / more money.

   (c) When Frank helped, the supplier of the grocer / has to / ask for / more money.

   (d) When Frank helped, the supplier of the grocers / has to / ask for / more money.

4. (a) After Jane interviewed the representative of the councillor / has to / get more / information.
   (b) After Jane interviewed the representative of the councillors / has to / get more / information.
   (c) After Jane interviewed, the representative of the councillor / has to / get more / information.
   (d) After Jane interviewed, the representative of the councillors / has to / get more / information.
5. (a) After Ann heckled the follower of the preacher / has to / leave the / building.
   (b) After Ann heckled the follower of the preachers / has to / leave the / building.
   (c) After Ann heckled, the follower of the preacher / has to / leave the / building.
   (d) After Ann heckled, the follower of the preachers / has to / leave the / building.
6. (a) After Will advised the assistant of the scientist / has to / resolve / a bad situation.
   (b) After Will advised the assistant of the scientists / has to / resolve / a bad situation.
   (c) After Will advised, the assistant of the scientist / has to / resolve / a bad situation.
   (d) After Will advised, the assistant of the scientists / has to / resolve / a bad situation.
7. (a) After Joe overtook the chauffeur of the shopkeeper / has to / brake all / of a sudden.
   (b) After Joe overtook the chauffeur of the shopkeepers / has to / brake all / of a sudden.
   (c) After Joe overtook, the chauffeur of the shopkeeper / has to / brake all / of a sudden.

(d) After Joe overtook, the chauffeur of the shopkeepers / has to / brake all / of a sudden.

8. (a) When Lee taught the student of the teacher / has to / listen / to the recordings.

   (b) When Lee taught the student of the teachers / has to / listen / to the recordings.

   (c) When Lee taught, the student of the teacher / has to / listen / to the recordings.

   (d) When Lee taught, the student of the teachers / has to / listen / to the recordings.

9. (a) After Kate investigated the relative of the witness / has to / deal with / the proceedings.

   (b) After Kate investigated the relative of the witnesses / has to / deal with / the proceedings.

   (c) After Kate investigated, the relative of the witness / has to / deal with / the proceedings.

   (d) After Kate investigated, the relative of the witnesses / has to / deal with / the proceedings.

10. (a) When Boris kissed the intern of the accountant / has to / think about / the repercussions.

    (b) When Boris kissed the intern of the accountants / has to / think about / the repercussions.

    (c) When Boris kissed, the intern of the accountant / has to / think about / the repercussions.

    (d) When Boris kissed, the intern of the accountants / has to / think about / the repercussions.

11. (a) While Ben followed the solicitor of the actor / has to / find the / documents.

    (b) While Ben followed the solicitor of the actors / has to / find the / documents.

(c) While Ben followed, the solicitor of the actor / has to / find the / documents.

(d) While Ben followed, the solicitor of the actors / has to / find the / documents.

12. (a) After Jessica interrogated the accomplice of the criminal / has to / go directly / to court.

(b) After Jessica interrogated the accomplice of the criminals / has to / go directly / to court.

(c) After Jessica interrogated, the accomplice of the criminal / has to / go directly / to court.

(d) After Jessica interrogated, the accomplice of the criminals / has to / go directly / to court.

13. (a) When Al attacked the bodyguard of the dancer / has to / find an / escape route.

(b) When Al attacked the bodyguard of the dancers / has to / find an / escape route.

(c) When Al attacked, the bodyguard of the dancer / has to / find an / escape route.

(d) When Al attacked, the bodyguard of the dancers / has to / find an / escape route.

14. (a) After Ian monitored the co-worker of the mechanic / has to / vacuum / the carpet.

(b) After Ian monitored the co-worker of the mechanics / has to / vacuum / the carpet.

(c) After Ian monitored, the co-worker of the mechanic / has to / vacuum / the carpet.

(d) After Ian monitored, the co-worker of the mechanics / has to / vacuum / the carpet.

15. (a) As Juliet approached the nurse of the patient / has to / welcome / the visitors.

(b) As Juliet approached the nurse of the patients / has to / welcome / the visitors.

(c) As Juliet approached, the nurse of the patient / has to / welcome / the visitors.

(d) As Juliet approached, the nurse of the patients / has to / welcome / the visitors.

16. (a) While Tom sketched the trainee of the painter / has to / prepare / the materials.

(b) While Tom sketched the trainee of the painters / has to / prepare / the materials.

(c) While Tom sketched, the trainee of the painter / has to / prepare / the materials.

(d) While Tom sketched, the trainee of the painters / has to / prepare / the materials.

17. (a) After Jane left the detective of the tycoon / has to / write down / the conversation.

(b) After Jane left the detective of the tycoons / has to / write down / the conversation.

(c) After Jane left, the detective of the tycoon / has to / write down / the conversation.

(d) After Jane left, the detective of the tycoons / has to / write down / the conversation.

18. (a) After Chris supervised the employee of the manager / has to / organise / the papers.

(b) After Chris supervised the employee of the managers / has to / organise / the papers.

(c) After Chris supervised, the employee of the manager / has to / organise / the papers.

(d) After Chris supervised, the employee of the managers / has to / organise / the papers.

19. (a) As Dan cursed the helper of the technician / has to / correct / the mistake.
    (b) As Dan cursed the helper of the technicians / has to / correct / the mistake.
    (c) As Dan cursed, the helper of the technician / has to / correct / the mistake.
    (d) As Dan cursed, the helper of the technicians / has to / correct / the mistake.

20. (a) While Jen checked the apprentice of the architect / has to / find faults / in the plans.
    (b) While Jen checked the apprentice of the architects / has to / find faults / in the plans.
    (c) While Jen checked, the apprentice of the architect / has to / find faults / in the plans.
    (d) While Jen checked, the apprentice of the architects/ has to / find faults / in the plans.

21. (a) While Matthew watched the teammate of the player / has to / control / the set-piece.
    (b) While Matthew watched the teammate of the players / has to / control / the set-piece.
    (c) While Matthew watched, the teammate of the player / has to / control / the set-piece.
    (d) While Matthew watched, the teammate of the players / has to / control / the set-piece.

22. (a) After Juan booed the admirer of the artist / has to / ignore / the outburst.
    (b) After Juan booed the admirer of the artists / has to / ignore / the outburst.
    (c) After Juan booed, the admirer of the artist / has to / ignore / the outburst.
    (d) After Juan booed, the admirer of the artists / has to / ignore / the outburst.

23. (a) When Shirley interrupted the fan of the singer / has to / stop playing / the record.

(b) When Shirley interrupted the fan of the singers / has to / stop playing / the record.

(c) When Shirley interrupted, the fan of the singer / has to / stop playing / the record.

(d) When Shirley interrupted, the fan of the singers / has to / stop playing / the record.

24. (a) As Alex called the secretary of the executive / has to / work on / the important files.

(b) As Alex called the secretary of the executives / has to / work on / the important files.

(c) As Alex called, the secretary of the executive / has to / work on / the important files.

(d) As Alex called, the secretary of the executives / has to / work on / the important files.

25. (a) After Virginia answered the cousin of the farmer / has to / think it / all over again.

(b) After Virginia answered the cousin of the farmers / has to / think it / all over again.

(c) After Virginia answered, the cousin of the farmer / has to / think it / all over again.

(d) After Virginia answered, the cousin of the farmers / has to / think it / all over again.

26. (a) When Laura paid the associate of the executive / has to / open a / new account.

(b) When Laura paid the associate of the executives / has to / open a / new account.

(c) When Laura paid, the associate of the executive / has to / open a / new account.

(d) When Laura paid, the associate of the executives / has to / open a / new account.

27. (a) While Jim inspected the superior of the soldiers / has to / review / the formation.

    (b) While Jim inspected the superior of the soldier / has to / review / the formation.

    (c) While Jim inspected, the superior of the soldiers / has to / review / the formation.

    (d) While Jim inspected, the superior of the soldier / has to / review / the formation.

28. (a) Before Dave left the chauffeur of the millionaire / has to / go to the / city centre.

    (b) Before Dave left the chauffeur of the millionaires / has to / go to the / city centre.

    (c) Before Dave left, the chauffeur of the millionaire / has to / go to the / city centre.

    (d) Before Dave left, the chauffeur of the millionaires / has to / go to the / city centre.

29. (a) After Peter cheated the client of the agent / has to / focus on / minor details.

    (b) After Peter cheated the client of the agents / has to / focus on / minor details.

    (c) After Peter cheated, the client of the agent / has to / focus on / minor details.

    (d) After Peter cheated, the client of the agents / has to / focus on / minor details.

30. (a) While Emily served the companion of the hiker / has to / look for / the toilets.

    (b) While Emily served the companion of the hikers / has to / look for / the toilets.

    (c) While Emily served, the companion of the hiker / has to / look for / the toilets.

(d) While Emily served, the companion of the hikers / has to / look for / the toilets.

31. (a) When Michael counselled the prisoner of the warden / has to / formulate / an appeal.

    (b) When Michael counselled the prisoner of the wardens / has to / formulate / an appeal.

    (c) When Michael counselled, the prisoner of the warden / has to / formulate / an appeal.

    (d) When Michael counselled, the prisoner of the wardens / has to / formulate / an appeal.

32. (a) When Jacob chased the robber of the pensioner / has to / jump out / of the window.

    (b) When Jacob chased the robber of the pensioners / has to / jump out / of the window.

    (c) When Jacob chased, the robber of the pensioner / has to / jump out / of the window.

    (d) When Jacob chased, the robber of the pensioners / has to / jump out / of the window.

33. (a) After Anna rang the collaborator of the researcher / has to / meet with / the professor.

    (b) After Anna rang the collaborator of the researchers / has to / meet with / the professor.

    (c) After Anna rang, the collaborator of the researcher / has to / meet with / the professor.

    (d) After Anna rang, the collaborator of the researchers / has to / meet with / the professor.

34. (a) When Claire visited the examiner of the graduate / has to / think about / the marks.

    (b) When Claire visited the examiner of the graduates / has to / think about / the marks.

(c) When Claire visited, the examiner of the graduate / has to / think about / the marks.

(d) When Claire visited, the examiner of the graduates / has to / think about / the marks.

35. (a) While Charlie painted the friend of the artist / has to / look at / the picture.

(b) While Charlie painted the friend of the artists / has to / look at / the picture.

(c) While Charlie painted, the friend of the artist / has to / look at / the picture.

(d) While Charlie painted, the friend of the artists / has to / look at / the picture.

36. (a) While Frank applauded the critic of the performer / has to / write down / some comments.

(b) While Frank applauded the critic of the performers / has to / write down / some comments.

(c) While Frank applauded, the critic of the performer / has to / write down / some comments.

(d) While Frank applauded, the critic of the performers / has to / write down / some comments.

37. (a) When Dick questioned the killer of the teenager / has to / admit to the / awful truth.

(b) When Dick questioned the killer of the teenagers / has to / admit to the / awful truth.

(c) When Dick questioned, the killer of the teenager / has to / admit to the / awful truth.

(d) When Dick questioned, the killer of the teenagers / has to / admit to the / awful truth.

38. (a) While Bernard coached the instructor of the gymnast / has to / perform / the routine.

(b) While Bernard coached the instructor of the gymnasts / has to / perform / the routine.

(c) While Bernard coached, the instructor of the gymnast / has to / perform / the routine.

(d) While Bernard coached, the instructor of the gymnasts / has to / perform / the routine.

39. (a) After Steve attacked the pilot of the passenger / has to / perform an / emergency landing.

(b) After Steve attacked the pilot of the passengers / has to / perform an / emergency landing.

(c) After Steve attacked, the pilot of the passenger / has to / perform an / emergency landing.

(d) After Steve attacked, the pilot of the passengers / has to / perform an / emergency landing.

40. (a) Before James examined the mentor of the speaker / has to / revise / the argumentation.

(b) Before James examined the mentor of the speakers / has to / revise / the argumentation.

(c) Before James examined, the mentor of the speaker / has to / revise / the argumentation.

(d) Before James examined, the mentor of the speakers / has to / revise / the argumentation.